

# **SINGLE SCATTERING CODE AGAUSX:THEORY, APPLICATIONS, COMPARISONS, AND LISTING**

**JULY 1980**

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function; (2) cycling over a range of wavelengths; (3) treating changes in hygroscopic particle sizes; (4) treating multicomponent aerosols differing in specific gravity and/or optical properties; (5) options whereby users can either input particle number density or mass density and mass concentration; (6) various size distribution models; and (7) automatic look up and/or interpolation of optical constants for liquid water. A comparison of AGAUSX with other Mie codes is also presented.

#### ACKNOWLEDGEMENTS

The work reported here was supported, in part, by the US Army Atmospheric Sciences Laboratory, Battelle Columbus Laboratories, and the New Mexico State University Computer Center. The authors also acknowledge the indirect assistance provided by Dr. C. W. Querfeld through discussions of the detailed numerical procedures which formed the starting point for the analysis presented above. Discussions with Dr. R. B. Gomez are also gratefully acknowledged. Thanks are also due to C. Amacker, N. Denzler, and S. Gregersen for their aid in constructing this report.

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## INTRODUCTION

The increasing need for information concerning the effects of aerosols upon electro-magnetic radiation passing through media containing these aerosols requires continual improvement of existing processes. As our understanding of these processes improves, the need for sophisticated numerical codes capable of accurately representing such theory continually increases. It is to this end that computer program AGAUSX (and its predecessors) has been constructed.

## PROGRAM AGAUSX

Experience acquired over a period of several years with various versions of the single scattering codes PGAUSS and AGAUS has revealed that users of such codes often tend to be over conservative in their choice of the number of radii at which Mie calculations are performed. Many single scattering codes require that the user specify some input parameter such as the total number of radii to be used. Unless a user has had a great deal of experience with choosing such parameters for various types of size distributions, there is a tendency to use many more radii than may be needed to obtain results at acceptable levels of accuracy. Since the overall running time of Mie codes may be greatly reduced by reducing the number of particle sizes treated, it is desirable to have a code in which one specifies an acceptable level of accuracy and which then uses only as many particle radius values as are needed to satisfy that requirement. Rather than specifying the number of radii, the user of AGAUSX must specify a "convergence" level DELTA. The quantity DELTA represents the minimum fractional accuracy that is acceptable for certain results of a run. In operation, AGAUSX then runs through the Mie calculations and integrations over size using only a few particle radii and obtains first estimates of extinction coefficients, etc. The size intervals are then reduced to one-half their former value and new estimates are calculated. If the new and old estimates agree to within  $(\text{DELTA} \times 100)$  percent, then AGAUSX ceases to treat additional particle sizes and proceeds to its final calculations. If the new estimate does not agree with the "old" one to within  $(\text{DELTA} \times 100)$  percent, the size interval is again cut in half and the calculations and comparisons are repeated. The cycling occurs repetitively

until either the convergence criterion is satisfied or until some precoded maximum number of values (513 for AGAUSX) for particle radius have been used.

It is believed that AGAUSX will represent a substantial advancement in aerosol modeling because it contains a large variety of size distributions, the possibility of modeling mixtures of aerosols with different optical properties, treats changes in particle size with variable relative humidity, is compatible with ACT<sup>+</sup> and will probably provide substantially shorter computation times than most existing aerosol codes. In addition AGAUSX has the capability of producing an analytic phase function when quick results of intermediate accuracy are desired.

In summary, program AGAUSX is a versatile, single scattering, state of the art computer code capable of performing the following:

(1) Provisions for producing (a) phase functions, (b) Legendre coefficients or (c) scattering fractions compatible with ACT.

(2) Provisions for producing an analytic phase function represented by Legendre coefficients.

(3) Provision for automatic cycling over a range of wavelengths and averaging of results over such a range of wavelengths.

(4) Provision for treating changes in hygroscopic particle sizes which may occur with variations in relative humidity.

(5) Provision for treating multicomponent aerosols differing in specific gravity and/or optical properties.

(6) Availability of options whereby users can either define particle number densities or let them be calculated from mass density and mass concentration.

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<sup>+</sup>Atmospheric Sciences Laboratory - Chemical Systems Laboratory - TRADOC Systems Analysis Agency, Battlefield/Smoke Obscuration Code.

(7) Availability of options whereby users can select various size distribution models, including:

(a) Log Normal

(b) Double Exponential

(c) Dermendjian's Model C

(d) Power Laws

(e) Khirgian - Mazin

(f) Modified Gamma whose control parameters may include liquid water content

(g) Four Bimodal Log-Normal

(h) Marshall - Palmer rain model

(i) User Supplied

(8) Inclusion of an internal subroutine to provide automatic look up and/or interpolation of optical constants for liquid water at wavelengths between  $0.35\mu\text{m}$  and  $200\mu\text{m}$ .

(9) Inclusion of built-in internal checks to warn users if certain computed quantities seem to be failing to converge and extended error messages associated with failures in the Mie routine.

Every effort has been made to insure that program AGAUSX is machine independent. To this end AGAUSX has been written in ASCII FORTAN, and is available in the form of BCD punched deck. Should the user have any questions, discover possible inaccuracies, or simply be desirous of a punched deck, please contact R. C. Shirkey, AUTOVON 258-4200 or (505) 678-4200.

## MIE THEORY

Mie theory<sup>1</sup> predicts the scattering by and the absorption in an isolated, discrete, homogeneous, isotropic sphere of diameter  $D$  with a known complex refractive index  $n = m - ik$  relative to the surrounding medium and illuminated by monochromatic radiant energy with wavelength  $\lambda$  in the surrounding medium. The theory is given in detail in standard texts and need not be repeated here. Instead, only those elements of theory needed for an understanding of the numerical algorithms used in AGAUSX are included.

Scatterers attenuate beams of radiant energy by scattering some of the energy into directions other than the incident or forward direction and by absorbing some of the incident energy within the body of the particle. The combined effect of pure scattering by the particle and true absorption within the particle is termed extinction. The amount of extinction, scattering and absorption by a single particle is given in terms of corresponding equivalent blocking areas or cross sections,  $C_{\text{ext}}$ ,  $C_{\text{sca}}$ , and  $C_{\text{abs}}$ , respectively. These cross sections depend only on the refractive index of the particle  $n = m - ik$  and the size parameter  $\alpha = 2\pi r/\lambda$ , where  $r$  is the particle radius, and  $\lambda$  is the wavelength.

The transmission,  $T$ , of a cloud of particles of geometric depth,  $d$ , and number density,  $N$ , is given by

$$T = e^{-\tau}, \quad (1)$$

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<sup>1</sup>G. Mie, 1908, "Considerations on the Optics of Turbid Media, Especially Colloidal Metal Sols," Ann Phys, 25

with the optical depth,  $\tau$ , given by

$$\tau = K_{\text{ext}} \cdot d, \quad (2)$$

where

$$K_{\text{ext}} = NC_{\text{ext}}. \quad (3)$$

The balance between loss by scattering and loss by absorption is frequently characterized by the albedo of single scattering  $\omega_o$ , given by

$$\omega_o = \frac{C_{\text{sca}}}{C_{\text{sca}} + C_{\text{abs}}} = \frac{C_{\text{sca}}}{C_{\text{ext}}}. \quad (4)$$

A scatterer with  $\tilde{\omega}_o = 1$  has no absorption and is termed a conservative scatterer. The albedo  $\tilde{\omega}_o$  gives the probability that a photon encountering the scatterer will be scattered into some direction including the incident direction.

Although the extinction by a cloud of particles is correctly given by equations (1) and (2), two implicit assumptions may lead to improper use of the equations. The optical depth  $\tau$  in equation (2) does not include losses caused by absorption in the medium surrounding the particles. This assumption obviously breaks down at wavelengths for which atmospheric gases absorb appreciably. The second assumption is that scattered photons never return to

the incident direction, i.e., that there is no multiple scattering. This effect becomes increasingly important as optical depths exceed  $\tau = 0.1$  for broad band propagation.<sup>2,3</sup> For laser wavelengths the effect is increasingly important as  $\tau$  goes beyond a value of 15.<sup>2,3</sup>

A final caution should be noted in regard to absorption within the particle. Although absorption within the particle is correctly determined by the wavelength-dependent imaginary part  $k$  of the refractive index  $n$ , the explicit mechanism which causes the absorption is usually not specified. Usually the absorption is joule heating and it is sometimes necessary to account for the isotropic black body radiation emitted by the scatterer when its temperature rises above that of its surroundings. There may also be circumstances when quantum transitions occur in the scatterer followed by emission at or near the same wavelengths. It is incumbent on the user of the numerical algorithms presented here to properly include these effects since they are not automatically accounted for in these algorithms.

All scattering properties of spheres are computed from  $m$  and  $k$ , and through the use of the induced electric and magnetic multipole moments of the sphere  $a_n$  and  $b_n$ , respectively. The moments are given by\*

$$a_n = \frac{\Psi'_n(n\alpha)\Psi_n(\alpha) - n\Psi_n(n\alpha)\Psi'_n(\alpha)}{\Psi'_n(n\alpha)\xi_n(\alpha) - n\Psi_n(n\alpha)\xi'_n(\alpha)}, \quad (5)$$

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<sup>2</sup>S. Hoijer, 1974, Atmospheric Attenuation of a Light Beam Due to Scattering and Absorption, Research Institute of National Defense, FOA-2-C-2659-E1-E2-E3-E4

<sup>3</sup>O. Steinvall, 1974, Computed MIE Scattering Properties for Laser Wavelengths in Various Atmospheric Media, Research Institute of National Defense, FOA-2-C-2662-E1-E3

\*Note that  $n$  is used as a subscript, an integer index, and a complex index of refraction when it is not a subscript.

and

$$b_n = \frac{n\Psi'_n(n\alpha)\Psi_n(\alpha) - \Psi_n(n\alpha)\Psi'_n(\alpha)}{n\Psi'_n(n\alpha)\xi_n(\alpha) - \Psi_n(n\alpha)\xi'_n(\alpha)}. \quad (6)$$

The prime denotes differentiation with respect to the argument. The  $\Psi_n(z)$  and  $\xi_n(z)$  functions are Ricatti-Bessel functions of the first and third kind, respectively, and are related to the spherical Bessel functions  $j_n(z)$  and  $n_n(z)$  by

$$\Psi_n(z) = zj_n(z), \quad (7)$$

and

$$\xi_n(z) = zj_n(z) - izn_n(z) = \Psi_n(z) + i\chi_n(z), \quad (8)$$

where

$$j_n(z) = \left(\frac{\pi}{2z}\right)^{1/2} J_{n+1/2}(z), \quad (9)$$



and

$$n_n(z) = \left(\frac{\pi}{2z}\right)^{1/2} N_{n+1/2}(z). \quad (10)$$

The function  $J_{n+1/2}(z)$  is the half integral order Bessel function; the function  $N_{n+1/2}(z)$  is the half integral order Neuman function.

The extinction cross section is computed from

$$C_{\text{ext}} = \frac{\lambda^2}{2\pi} \sum_{n=1}^{\infty} (2n+1) \operatorname{Re} (a_n + b_n), \quad (11)$$

and the scattering cross section from

$$C_{\text{sca}} = \frac{\lambda^2}{2\pi} \sum_{n=1}^{\infty} (2n+1) [|a_n|^2 + |b_n|^2]. \quad (12)$$

The various cross sections are the basic quantities used in scattering problems, but they are not the quantities usually computed directly from Mie algorithms. Instead, it is more convenient to compute dimensionless efficiency factors  $Q_{\text{ext}}$  and  $Q_{\text{sca}}$ , which depend on  $n$ ,  $k$ , and  $\alpha$ , and which are multiplied by the geometrical sphere cross section to obtain the true cross section  $C_i = \pi r^2 Q_i$ . Thus,

$$Q_{\text{ext}} = \frac{2}{\alpha^2} \sum_{n=1}^{\infty} (2n+1) \operatorname{Re} (a_n + b_n), \quad (13)$$

and

$$Q_{\text{sca}} = \frac{2}{\alpha^2} \sum_{n=1}^{\infty} (2n+1) [|a_n|^2 + |b_n|^2]. \quad (14)$$

Although the cross sections account for the energy removed from the forward beam, they do not give any information about where the scattered photons go. This information is contained in scattering amplitudes and intensity factors which relate the flux density scattered through an angle  $\theta$  relative to the incident flux density. There are two amplitudes,  $S_1(\theta)$  and  $S_2(\theta)$ , and the intensity factors  $i_1(\theta)$  and  $i_2(\theta)$ , which correspond to light respectively polarized perpendicular and parallel to the plane of the scattering defined by the direction of incidence and the direction of scattering.

The intensity factors are related to the scattering amplitudes by

$$i_1(\theta) = |S_1(\theta)|^2, \quad (15)$$

and

$$i_2(\theta) = |S_2(\theta)|^2. \quad (16)$$

The amplitudes come from the multipole moments through

$$S_1(\theta) = \sum_{n=1}^{\infty} \frac{2n+1}{n(n+1)} [a_n \pi_n(\theta) + b_n \tau_n(\theta)], \quad (17)$$

and

$$S_2(\theta) = \sum_{n=1}^{\infty} \frac{2n+1}{n(n+1)} [b_n \pi_n(\theta) + a_n \tau_n(\theta)], \quad (18)$$

and angular factors  $\pi_n(\theta)$  and  $\tau_n(\theta)$  defined in terms of associated Legendre functions:

$$\pi_n(\theta) = P_n^1(\cos \theta) / \sin \theta; \quad (19)$$

$$\tau_n(\theta) = \frac{dP_n^1(\cos \theta)}{d\theta} . \quad (20)$$

The amplitudes have relative phase  $\delta = \arg S_1 - \arg S_2$ .  
Alternative expressions frequently used are

$$\pi_n(\theta) = \frac{dP_n(\cos \theta)}{d(\cos \theta)} , \quad (21)$$

and

$$\pi_n(\theta) = \cos \theta \cdot \pi_n(\theta) - \sin^2 \theta \cdot \frac{d\pi_n(\theta)}{d(\cos \theta)} , \quad (22)$$

where

$$P_n(\cos \theta) = \frac{1}{2^n n!} \frac{d^n}{d \cos^n \theta} (\cos^2 \theta - 1)^n . \quad (23)$$

These functions satisfy the following recurrence relations:

$$\pi_n(\theta) = \cos \theta \frac{(2n-1)}{(n-1)} \pi_{n-1}(\theta) - \frac{n}{n-1} \pi_{n-2}(\theta), \quad (24)$$

and

$$\tau_n(\theta) = \cos \theta [\pi_n(\theta) - \pi_{n-2}(\theta)] - (2n-1) \sin^2 \theta \pi_{n-1}(\theta) + \tau_{n-2}(\theta). \quad (25)$$

The scattering cross section measures the ability of a particle to scatter light, and it is to be expected that  $C_{sca}$  is obtained from an integral over the scattering intensity factors. Equation (12) follows from

$$C_{sca} = \frac{\lambda^2}{4\pi} \int_{-1}^1 [i_1(\theta) + i_2(\theta)] d\cos\theta. \quad (26)$$

Although the intensity factors themselves may be used in scattering calculations, they are primarily suited for computing flux densities, and it is frequently more convenient to measure and compute scattered light in terms of radiances. Radiances do not have the  $1/r^2$  dependence, and it is therefore unnecessary to know the distance from the scatterer to the detector if the detector field of view is small and is filled by the scattering cloud. The phase function,  $p(\theta)$ , gives a radiance,  $I$ , scattered into the  $\theta$  direction in terms of the radiance  $I_0$  incident on the particle. The phase function is dimensionless and is defined here as

$$p(\theta) = \frac{\lambda^2}{2\pi C_{\text{ext}}} [i_1(\theta) + i_2(\theta)]. \quad (27)$$

The normalized phase function  $p(\theta)d\Omega/4$  gives the probability of a photon being scattered through an angle  $\theta$  into an element of solid angle  $d\Omega = d\phi d(\cos \theta)$ . The integral of the normalized phase function is the single scattering albedo  $\tilde{\omega}_0$ , which gives the probability that the photon is scattered:

$$\tilde{\omega}_0 = \frac{1}{4\pi} \int_0^{2\pi} \int_{-1}^1 p(\theta) d\phi d\cos\theta = \frac{\lambda^2}{4\pi C_{\text{ext}}} \int_{-1}^1 [i_1(\theta) + i_2(\theta)] d\cos\theta, \quad (28)$$

or

$$\tilde{\omega}_0 = C_{\text{sca}}/C_{\text{ext}}. \quad (29)$$

The phase function contains a sum over the polarization states implicit in the  $i_1$  and  $i_2$  intensity factors, and is thus unsuitable for describing the polarization of the scattered light.

The phase function can also be represented by a Legendre series:

$$p(\theta) = \sum_{\ell=0}^{n-1} \tilde{\omega}_\ell P_\ell(\cos\theta), \quad (30)$$

where the Legendre expansion coefficients  $\tilde{\omega}_\ell$  are given by

$$\tilde{\omega}_\ell = \frac{(2\ell+1)}{2} \int_{-1}^1 p(\theta) P_\ell(\cos\theta) d(\cos\theta), \quad (31)$$

and  $P_\ell(\cos\theta)$  are the usual Legendre polynomials.

#### ANALYTIC PHASE FUNCTION

A new analytic phase function has been constructed that approximates the computed phase function. This analytic phase function is comprised of two analytic functions; a new function up to angle  $\theta_1$  and a modified Henyey - Greenstein analytic function for angles greater than  $\theta_1$ . This new analytic phase function is called the Goedecke-Henyey-Greenstein analytic phase function and will subsequently be referred to as the GHG phase function.

The GHG phase function has the following analytic form:

$$\bar{p}(\mu) = \begin{cases} \tilde{\omega}_0 \left[ \frac{\alpha}{2} \frac{1-g^2}{(1-2g\mu+g^2)^{3/2}} + \left(1 - \frac{\alpha}{2}\right) \frac{1}{(1-2g\mu+g^2)^{1/2}} \right], & 1 \geq \mu \geq \mu_1, \\ \tilde{\omega}_0 \beta \frac{1-g^2}{(1-2g\mu+g^2)^{3/2}}, & \mu_1 \geq \mu \geq -1, \end{cases} \quad (32a,b)$$

where  $\mu = \cos\theta$ ,  $\tilde{\omega}_0$  is the albedo for single scattering, and  $\bar{P}(\mu)$  is the phase function at  $\mu$ . The bar above quantities denotes approximations. Here,  $g, \alpha, \beta, \mu_1$  are parameters that must be fixed and are evaluated as follows:

Using equation 32a as a generating function, we may write the equivalent equation

$$\bar{P}(\mu) = \tilde{\omega}_0 \sum_{N=0}^{\infty} (\alpha N + 1) g^N P_N(\mu), \quad (33a)$$

or

$$\bar{P}(\mu) \equiv \sum_{N=0}^{\infty} \bar{\omega}_N P_N(\mu), \quad (33b)$$

where the  $P_N(\mu)$ 's are the Legendre polynomials, and again the bar above the symbols denotes approximations. Making use of equations 32a and 33a we now solve for  $\alpha$  and  $\beta$  by forcing the equations to match at  $\mu = 1$ . This is done because forward scattering is usually dominant for large Mie size parameters. Solve simultaneously

$$\bar{P}(1) = \frac{\tilde{\omega}_0}{(1-g)^2} \left[ \frac{\alpha}{2} (1+g) + \left(1 - \frac{\alpha}{2}\right) (1-g) \right], \quad (34a)$$



$$\tilde{\omega}_2 = \bar{\omega}_2 = \tilde{\omega}_0 (\alpha + 1)g^2. \quad (34b)$$

In equation (34b) we have forced the approximate value,  $\bar{\omega}_2$ , to equal the exact value,  $\tilde{\omega}_2$ .  $\tilde{\omega}_2$  has been used, as opposed to  $\tilde{\omega}_1$ , as it was found that the match produced by  $\tilde{\omega}_1 = \tilde{\omega}_0(\alpha+1)g$  will not work for all cases. Since we expect that for  $\mu < \mu_1$  the actual phase function, and therefore the HG part of the GHG phase function, is small compared to its values for  $\mu > \mu_1$ , we take the values of  $\alpha$  and  $g$ , found by simultaneously solving equations 34a and b, as our working values.

Ideally  $\mu_1$  could be found by setting equation 34a equal to zero; however, using a value of  $\mu_1$  determined in such a manner would produce an unnatural dip in the phase function where we match 32a to 32b. Therefore we take  $\mu_1$  to be that value of  $\mu$  for which the phase function represented by equation (32a) first goes negative (the phase function represented by equation 32a may not go negative, but dependent upon the various parameters it may).  $\beta$  is found by matching 32a to 32b at  $\mu = \mu_1$ . This yields

$$\beta = \frac{\alpha}{2} + (1 - \frac{\alpha}{2})(1 - 2g\mu_1 + g^2)/(1 - g^2) > 0. \quad (35)$$

Since  $\mu_1$  is now known a priori the value of  $\beta$  will be approximate. As  $\beta > 0$  then  $\bar{P}(\mu) > 0$  for all  $\mu$  and is a continuous function of  $\mu$ . We must now determine the approximate Legendre coefficients,  $\bar{\omega}_N$ . This is done by using the inversion formula

$$\bar{\omega}_N = \frac{2N+1}{2} \int_{-1}^1 \bar{P}(\mu) P_N(\mu) d\mu. \quad (36)$$

If  $\mu_1 > -1$ , implying usage of the HG phase function, none of the  $\bar{\omega}_N$  will exactly match the exact or 'true'  $\tilde{\omega}_N$ . Since it is most important that an approximate phase function have the correct single scattering albedo,  $\tilde{\omega}_0$ , we redefine

$$\bar{P}(\mu) \equiv \frac{\tilde{\omega}_0}{\bar{\omega}_0} \bar{P}(\mu), \quad (37)$$

and therefore,

$$\begin{aligned} \bar{\omega}'_N &= \frac{2N+1}{2} \int_{-1}^1 \bar{P}(\mu) P_N(\mu) d\mu, \\ &= \frac{\tilde{\omega}_0}{\bar{\omega}_0} \bar{\omega}_N. \end{aligned} \quad (38)$$

This guarantees that  $\bar{\omega}_0 = \tilde{\omega}_0$ , but because  $\alpha$ ,  $g$ , and  $\beta$  are approximate,  $\bar{\omega}_2$  will not match  $\tilde{\omega}_2$  exactly. As long as the HG part of the GHG phase is small, the mismatch between  $\bar{\omega}_2$  and  $\tilde{\omega}_2$  will be small.

In all the above cases it is necessary to calculate only two of the coefficients in the Legendre expansion of the phase function,  $\tilde{\omega}_0$  and  $\tilde{\omega}_1$  or  $\tilde{\omega}_0$  and  $\tilde{\omega}_2$ . This may be done directly in terms of the  $a_n$  and  $b_n$  coefficients of the Legendre series occurring in Mie theory without evaluating the exact phase function of any angle.

We want the phase function incident for natural light to satisfy

$$\int_{-1}^1 \overline{P}(\mu) d\Omega = 4\pi \tilde{\omega}_0 = 2\pi \int_{-1}^1 P(\mu) d\mu = 4\pi \frac{C_{\text{scat}}}{C_{\text{ext}}}, \quad (39)$$

where  $C$  is the total cross section for scattering and extinction, respectively. In the notation of van de Hulst<sup>4</sup>

$$C_{\text{scat}} = \frac{1}{k^2} \int F(\theta, \phi) d\Omega. \quad (40)$$

So, if we put

$$P(\mu) = \frac{K}{2\pi} \int_0^{2\pi} F(\theta, \phi) d\phi, \quad (41)$$

then

$$\int P(\mu) d\Omega = K k^2 C_{\text{scat}}, \quad (42)$$

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<sup>4</sup>H. C. van de Hulst, 1957, Light Scattering by Small Particles, John Wiley and Sons, Inc., New York

or

$$K = \frac{4}{k^2 C_{\text{ext}}} , \quad (43)$$

and therefore

$$P(\mu) = \frac{2}{k^2 C_{\text{ext}}} \int_0^{2\pi} F(\theta, \phi) d\phi. \quad (44)$$

Now  $F(\theta, \phi) = i_1(\theta) \sin^2 \phi + i_2(\theta) \cos^2 \phi$ , hence

$$P(\mu) = \frac{1}{k^2 C_{\text{ext}}} [i_1(\theta) + i_2(\theta)], \quad (45)$$

where  $i_{1,2}(\theta) = |S_{1,2}(\theta)|^2$

and

$$S_1(0) = S_2(0) = \frac{1}{2} \sum_{n=1}^{L \rightarrow \infty} (2n+1) (a_n + b_n). \quad (46)$$

Therefore,

$$P(1) = \frac{1}{k^2 C_{\text{ext}}} \frac{1}{2} \left| \sum_{n=1}^L (2n+1) (a_n + b_n) \right|^2 = \frac{2}{k^2 C_{\text{ext}}} |S_1(0)|^2, \quad (47)$$

where

$$C_{\text{ext}} = \frac{4\pi}{k^2} \text{Re} \left[ \frac{1}{2} \sum_{n=1}^{L \rightarrow \infty} (2n+1) (a_n + b_n) \right] = \frac{4\pi}{k^2} \text{Re} [S_1(0)]. \quad (48)$$

This allows direct calculation of  $P(1)$  in terms of  $a_n$  and  $b_n$ . We now need expressions for  $\tilde{\omega}_1$  and/or  $\tilde{\omega}_2$  in terms of the  $a_n$  and  $b_n$ . These are given by Chu and Churchill.<sup>5\*</sup> In terms of the Mie coefficients  $a_n$ ,  $b_n$ , these expressions are:

$$\tilde{\omega}_1 = \frac{3}{x^2 Q_{\text{ext}}} \sum_{n=1}^{\infty} \left[ -\frac{2n(n+2)}{(n+1)} (a_n a_{n+1}^* + b_n b_{n+1}^* + a_{n+1} a_n^* + b_{n+1} b_n^*) + \frac{2(2n+1)}{n(n+1)} (a_n b_n^* + a_n^* b_n) \right], \quad (49)$$

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<sup>5</sup>C. M. Chu and S. W. Churchill, 1955, "Representation of the Angular Distribution of Radiation Scattered by a Spherical Particle," J Opt Soc Am, 45:958

\*There appears to be a typographical error in Chu and Churchill's work on the bottom of page 961:  $j+k-n = 2r+1$  should read  $j+k-n = 2r-1$ .

$$\begin{aligned} \tilde{\omega}_2 = & \frac{4}{x^2 Q_{\text{ext}}} \sum_{n=1}^{\infty} \left[ \frac{5}{2} \frac{(n(n+1)-3)^2 (2n+1)}{n(n+1)(2n+3)(2n-1)} \text{Re}(a_n^* a_n + b_n^* b_n) \right. \\ & \left. + \frac{15}{2} \frac{n(n+3)}{(2n+3)} \text{Re}(a_{n+2}^* a_n + b_{n+2}^* b_n) + \frac{15}{n+1} \text{Re}(a_{n+1}^* b_n + b_{n+1} a_n^*) \right], \end{aligned} \quad (50)$$

where  $x = 2\pi r/\lambda$ ,  $Q_{\text{ext}} = C_{\text{ext}}/(\pi r^2)$ , and  $r$  is the particle radius.

#### RELATIONSHIPS BETWEEN SCATTERING FRACTIONS AND PHASE FUNCTIONS

Among the objectives of the work done here was the conversion of the single scattering code AGAUS into a form which produced the types of data required by the ACT Battlefield/Smoke Obscuration Model while retaining a variety of options previously developed for AGAUS. That conversion required that AGAUS be given the additional capabilities of predicting (a) attenuation coefficients or cross sections in units of square meters per milligram of aerosol material, and (b) so-called "scattering fractions" per unit aerosol mass. In order to avoid possible confusions on the precise relationships between "scattering fractions" and the customary quantities used in Mie theory, those relationships will be summarized below before proceeding to a discussion of the evaluation of AGAUSX.

The so-called "phase functions", denoted here by  $P_f(\mu)$  and "scattering fractions"  $S_f(\theta)$  are both derived from the average scattered intensities  $(I_1 + I_2)/2$  defined in Mie theory. The two quantities are related to one another for calculations associated with a single wavelength by a simple multiplicative factor, but they have different interpretations and applications.

Let  $I(\alpha, m, k, \theta)$  be the average of the intensities  $i_1(\theta)$  and  $i_2(\theta)$  for scattering at angle  $\theta$  from a sphere whose Mie-size parameter is  $\alpha = 2\pi r/\lambda$ , and whose complex index of refraction is  $n = m - ik$ . Furthermore, let  $n(r)dr$  be the relative number of aerosol particles with radii between  $r$  and  $(r+dr)$ , and let  $Q_{\text{ext}}(\alpha, m, k)$  and  $Q_{\text{sca}}(\alpha, m, k)$  respectively be the total extinction and

scattering efficiency factors as defined by van de Hulst.<sup>4</sup>

Now, define the quantities  $\bar{I}$ ,  $\bar{C}_{\text{ext}}$  and  $\bar{C}_{\text{sca}}$  as follows:

$$\bar{C}_{\text{ext}} = \frac{1}{N_T} \int_{r=0}^{\infty} \pi r^2 n(r) Q_{\text{ext}}(\alpha, m, k) dr, \quad (51)$$

$$\bar{C}_{\text{sca}} = \frac{1}{N_T} \int_{r=0}^{\infty} \pi r^2 n(r) Q_{\text{sca}}(\alpha, m, k) dr, \quad (52)$$

$$\bar{I}(\theta) = \frac{1}{N_T} \int_{r=0}^{\infty} I(\alpha, m, k, \theta) n(r) dr, \quad (53)$$

where

$$N_T = \int_{r=0}^{\infty} n(r) dr. \quad (54)$$

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<sup>4</sup>H. C. van de Hulst, 1957, Light Scattering by Small Particles, John Wiley and Sons, Inc., New York

The "phase function" as defined in program(s) AGAUS is given by

$$P_f(\theta) = \frac{\lambda^2}{\pi \bar{C}_{\text{ext}}} \bar{I}(\theta) , \quad (55)$$

as has the property that

$$\int_{\phi=0}^{2\pi} \int_{\theta=0}^{\pi} P_f(\theta) d\phi d(\cos\theta) = 4\pi \frac{\bar{C}_{\text{sca}}}{\bar{C}_{\text{ext}}} \equiv 4\pi \tilde{\omega}_0 , \quad (56)$$

where  $\tilde{\omega}_0$  is called "the albedo for single scattering".

The "scattering fractions"  $S_f(\theta)$  are defined by

$$S_f(\theta) = \left( \frac{\lambda}{2\pi} \right)^2 N_T \bar{I}(\theta) , \quad (57)$$

and  $S_f(\theta)$  has the property

$$\int_{\phi=0}^{2\pi} \int_{\theta=0}^{\pi} S_f(\theta) d\phi d(\cos\theta) = \bar{C}_{\text{sca}} \cdot N_T = (C_{\text{sca}})_{\text{total}} , \quad (58)$$

wherein  $(C_{\text{sca}})_{\text{total}}$  is the total scattering cross section per unit mass of aerosol material.



Thus, it will be seen that

$$S_f(\theta) = \left(\frac{1}{4\pi} N_T \bar{C}_{\text{ext}}\right) P_f(\theta). \quad (59)$$

The ACT Model is coded with the assumption that  $(C_{\text{sca}})_{\text{total}}$  as derived from  $S_f(\theta)$  will have units of square meters per milligram. Programs AGAUS9 and AGAUSX, (see below) on the other hand are coded in what are basically CGS units. Conversion from  $I(\theta)$  to  $S_f(\theta)$  in the ACT normalization therefore requires a unit-conversion factor for  $\lambda^2$  from  $\mu\text{m}$  to  $\text{m}$ , and for  $N_T$  from  $\text{cm}^{-3}$  to  $\text{m}^{-3}$ , i.e.,

$$[\lambda(\mu\text{m})]^2 N_T(\text{cm}^{-3}) \times (10^{-6} \frac{\text{m}}{\mu\text{m}})^2 \times 10^6 \frac{\text{cm}^3}{\text{m}^3}. \quad (60)$$

Thus, a factor  $10^{-6}$  is required to convert the scattering fractions from the internal units of program AGAUS to the units expected by ACT.

#### VERIFICATION OF COMPUTER CODES

Evaluation of AGAUS9:\* Once the relationships between the Mie intensities,  $i_1$  and  $i_2$  described above were clearly elucidated, it seemed that it would be a straightforward task to convert AGAUS from the computation of phase functions to the calculation of scattering fractions. When the appropriate conversions were completed, the new version, AGAUS9, was run using, as nearly as could be

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\*AGAUS9 is the parent code for AGAUSX and they basically differ only in the manner in which the number of radial increments for integration over the size distributions are chosen.

determined, the same aerosol model for which results were found in the ACT documentation.\* The particular model used was a log normal distribution for white phosphorus (WP) smoke ( $\bar{r} = 0.37\mu\text{m}$ ,  $\sigma = 1.54\mu\text{m}$ ), 200 particle radii between minimum and maximum values of 0.005 and 1.0 $\mu\text{m}$ , respectively, a mass density of 1.87 gm/cc, a particle number density of  $1.276345 \times 10^3 \text{ cm}^{-3}$ , and complex index of refraction  $n = 1.43 - 0i$ . Computations were performed at 7 wavelengths (0.40, 0.45, 0.50, 0.55, 0.60, 0.65 and 0.70 $\mu\text{m}$ ), and the scattering fractions were arithmetically averaged over wavelength. Some of the results are presented in table 1. Only a cursory examination of that table is needed to observe that the AGAUS9 results were not in very good agreement with those found in the ACT documentation. This comparison was unexpected, because the basic AGAUS code had previously been found to give much better agreement with other Mie codes than is seen in table 1.

Because thorough reviews of the program listings failed to shed any light on the reasons for such large apparent discrepancies it was decided that comparisons of computations made at a single wavelength (rather than after averaging over several wavelengths) were highly desirable. The problem there was that the ACT documentation did not contain any single wavelength results. Since that avenue for testing of AGAUS9 was closed, some other approach was needed, and was found through a copy of the MIE2 code.

The aerosol model used to generate table 1 was then passed through both AGAUS9 and the MIE2 code using a wavelength of 0.40 $\mu\text{m}$  only. The results of those two runs are shown in table 2.\*\*

Examination of table 2 reveals that the AGAUS9 results and the MIE2 results are in much better agreement than those seen in table 1. Whereas table 2 shows discrepancies even in the first digit at many scattering angles, table 2

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\*The label ACT is used to refer to the document entitled "The Effectiveness of Obscuring Smokes," by Johnson, Forney and Dolce, and unpublished description of the JTOG/ME smoke obscuration model which was obtained from R. B. Gomez of ASL.

\*\*The results of MIE2 have been multiplied by a factor of  $10^2$  to offset different normalizations used in ACT and AGAUS9.

TABLE 1

COMPARISON OF SCATTERING FRACTIONS FROM AGAUS9  
AND ACT REPORT AS AVERAGED FOR A SEVEN WAVELENGTH RUN

<u>Scattering Angle</u>	<u>Scattering Fractions</u>	<u>Scattering Fractions ACT Report</u>
0°	0.5840074-02	0.530822-02
10°	0.3385669-02	0.294243-02
20°	0.1236144-02	0.961893-03
30°	0.5525204-03	0.419528-03
40°	0.2882904-03	0.254840-03
50°	0.1637546-03	0.176892-03
60°	0.9840574-04	0.114931-03
70°	0.6277324-04	0.706178-04
80°	0.4262488-04	0.445657-04
90°	0.3097364-04	0.309732-04
100°	0.2429897-04	0.249208-04
110°	0.2086846-04	0.237614-04
120°	0.2023009-04	0.265251-04
130°	0.2267312-04	0.330425-04
140°	0.3014750-04	0.446135-04
150°	0.4592933-04	0.637035-04
160°	0.6781825-04	0.883152-04
170°	0.4512012-04	0.678717-04
180°	0.6003613-04	0.836141-04

TABLE 2

COMPARISON OF RESULTS FROM RUNS OF AGAUS9  
AND MIE2 AT A SINGLE WAVELENGTH

<u>Scattering Angle</u>	<u>Scattering Fractions</u>	<u>I*<sub>avg</sub> (MIE2)</u>
0°	8.215439-03	8.215442-03
10°	3.341243-03	3.341238-03
20°	8.565565-04	8.565530-04
30°	4.126651-04	4.126640-04
40°	2.452253-04	2.452247-04
50°	1.503114-04	1.503111-04
60°	9.399925-05	9.399906-05
70°	6.098411-05	6.098398-05
80°	4.167272-05	4.167267-05
90°	3.019892-05	3.019886-05
100°	2.333270-05	2.333268-05
110°	1.957286-05	1.957282-05
120°	1.854355-05	1.854351-05
130°	2.096545-05	2.096542-05
140°	2.942918-05	2.942910-05
150°	4.947500-05	4.947498-05
160°	8.643879-05	8.643865-05
170°	6.208783-05	6.208780-05
180°	7.644555-05	7.644557-05

\*The MIE2 results have been multiplied by  $10^2$  to normalize them in the same way as found in the SOM document.

shows that AGAUS9 and MIE2 agree to at least give and often six significant digits--the nominal accuracy which is used in terminating Mie series calculations in AGAUS9. The disagreements found in table 1 should be interpreted as differences either in the procedure for the integration over wavelength or the fact that a single precision version of MIE2 was used in the generation of the ACT data.

To avoid drawing erroneous conclusions on the cross-agreements between results produced by AGAUS9 and MIE2 on the basis of a single aerosol model, additional comparisons were made using a quite different aerosol model. The model chosen for this "test" was a "modified" gamma distribution:

$$f(r) = Ar^{\alpha} \exp(-Br^{\gamma}), \quad [\text{for MIE2}] \quad (61)$$

with  $A = 1.0396 \times 10^8$ ,  $\alpha = 7.5$ ,  $B = 333333$  and  $\gamma = 1.0$ . The input data used by AGAUS9 are the particle number density  $N_T$  and mode radius  $r_c$ , rather than  $A$  and  $B$ , but the various quantities are related to one another through:

$$r_c = \left(\frac{\alpha}{\gamma B}\right)^{1/\gamma} \quad \text{and} \quad N_T = AB^{-\left(\frac{\alpha+1}{\gamma}\right)} \Gamma\left(\frac{\alpha+1}{\gamma}\right). \quad (62)$$

For this comparison the minimum and maximum particle radii were taken to be  $0.01\mu\text{m}$  and  $1.5\mu\text{m}$ , respectively, and 200 individual values of particle radii were used. The run was made at a wavelength of  $0.6\mu\text{m}$  using  $n = 1.53 - 0.006i$ . Some results of the first runs of this type will be found in table 3.

Contrary to the excellent agreement found between MIE2 and AGAUS9, the data found in table 3 did not agree as well as had been expected being good only to about 4 digits. Further analysis indicated that the most probable source of these disagreements lay in the fact that AGAUS9 and MIE2 did not choose the

TABLE 3

COMPARISON OF SCATTERING FRACTIONS CALCULATED BY MIE2  
AND AGAUS9 FOR A MODIFIED GAMMA DISTRIBUTION

Scattering Angle	Scattering Fractions	I* <sub>avg</sub> (MIE2)
0°	9.254421-08	9.254768-08
10°	7.620680-08	7.620913-08
20°	4.470319-08	4.470374-08
30°	2.156754-08	2.156747-08
40°	1.038258-08	1.038255-08
50°	5.626184-09	5.626226-09
60°	3.415889-09	3.415935-09
70°	2.236736-09	2.236776-09
80°	1.555144-09	1.555170-09
90°	1.149602-09	1.149602-09
100°	9.113908-10	9.114065-10
110°	7.876338-10	7.876470-10
120°	7.656564-10	7.656688-10
130°	8.657526-10	8.657658-10
140°	1.074210-09	1.074245-09
150°	1.193137-09	1.193200-09
160°	1.134702-09	1.134755-09
170°	1.502157-09	1.502236-09
180°	1.969069-09	1.969203-09

\*The MIE2 results have been multiplied by  $10^2$  to normalize them in the same way as found in the ACT document.

values of particle radii actually used in the calculation in the same way. Slight alterations to remove these differences were then made in AGAUS9, and the calculations were repeated, yielding the data presented in table 4.

In table 4 discrepancies between the AGAUS9 and MIE2 results again appear only in the fifth or sixth significant digit.

The above results indicate once again that code AGAUS9 is quite capable of yielding results which are as reliable as those of MIE2. The changes in AGAUS9 needed to bring about the level of agreement seen in table 4 involved only the choice of the values of the 200 radii used, and illustrates that the method of choosing the radii can have a significant effect on the values of the scattering fractions even when a relatively large number of radii are used. The matter will be discussed further in a subsequent section of this document.

#### EVALUATION OF PROGRAM AGAUSX

Introduction: In the development of the actual coding of program AGAUSX, continuous testing and comparison of results produced by the new codes and those yielded by other single scattering codes was carried out. The findings of a few such comparisons will be given next.

The supplementary codes used for evaluation of AGAUSX were the codes AGAUS9, and the code MIE2. In order to avoid the problem of deciding which of the three codes used was "correct" in the event that no two agreed well, all codes were run using aerosol models for which independent results could be found in Deirmendjian's book.<sup>6</sup> The specific models used for comparison runs were Deirmendjian's cloud models C.1 and C.3 at a wavelength of  $0.7\mu\text{m}$ . Additional comparison runs were made at  $10.6\mu\text{m}$  using a simulated hygroscopic smoke model<sup>7</sup>

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<sup>6</sup>D. Deirmendjian, 1969, Electromagnetic Scattering on Spherical Polydispersions, American Elsevier Publishing Co., Inc., New York

<sup>7</sup>A. Miller, R. C. Shirkey, E. Gemoets and G. H. Goedecke, 1978, Investigations on the Prediction of Infrared Transmission and Emission by Clear and Aerosol Laden Atmospheres, NMSU Department of Physics, Final Report for Contract DAEA18-77-C-00003

TABLE 4

COMPARISON OF SCATTERING FRACTIONS PRODUCED BY MIE2 AND A SPECIAL VERSION<sup>†</sup>  
OF AGAUS9 FOR A MODIFIED GAMMA DISTRIBUTION

<u>Scattering Angle</u>	<u>Scattering Fractions</u>	<u>I*<sub>avg</sub> (MIE2)</u>
0°	9.254772-08	9.254768-08
10°	7.620918-08	7.620913-08
20°	4.470380-08	4.470374-08
30°	2.156751-08	2.156747-08
40°	1.038257-08	1.038255-08
50°	5.626233-09	5.626226-09
60°	3.415938-09	3.415935-09
70°	2.336777-09	2.336776-09
80°	1.555171-09	1.555170-09
90°	1.149623-09	1.149622-09
100°	9.114071-10	9.114065-10
110°	7.876480-10	7.876470-10
120°	7.656697-10	7.656688-10
130°	8.657668-10	8.657658-10
140°	1.074245-09	1.074245-09
150°	1.193200-09	1.193200-09
160°	1.134755-09	1.134755-09
170°	1.502236-09	1.502236-09
180°	1.969203-09	1.969203-09

<sup>†</sup> Particle radii selected the same way as in MIE2.

\* The MIE2 results have been multiplied by  $10^2$  to normalize them in the same way as found in the SOM document.



and several values of relative humidity. The latter comparisons involved only program AGAUS9 and AGAUSX. The objectives of all comparisons were not only to show that AGAUSX was working properly, but also to determine whether or not it would, in fact, offer significant reductions in overall running time.

Water Cloud Model Comparisons: Comparison runs of codes AGAUS9, AGAUSX and MIE2 for cloud models C.1 and C.3 were made using the same range of radii quoted for Deirmendjian's tables T.36 and T.30. In order to assure that any conclusions drawn about relative computation times would be valid in the context of ACT usage, scattering fractions were calculated at  $2^\circ$  increments between scattering angles of  $0^\circ$  and  $180^\circ$  in these runs. AGAUSX was also run for model C.1 using several different values of the convergence level DELTA.

Table 5 presents some of the results obtained for cloud model C.1. The scattering fraction entries for the "Deirmendjian" column were obtained by averaging his  $P_1$  and  $P_2$ , and multiplying by the appropriate conversion factor. The AGAUSX run listed used  $\text{DELTA} = 0.01$ . Examination of the tabulated data shows that none of the three runs yields exactly the same extinction coefficient that was printed by Deirmendjian, but all were within 0.3 percent of his results. Unfortunately, Deirmendjian's table T.36 did not include angles at  $2^\circ$  increments, so only forward and backward scattering fractions could be inferred accurately. It will be seen that all three codes gave scattering fractions which agreed well in the  $\theta = 0^\circ$  direction, but the results are obviously not identical. The variations are, however, quite a bit larger at other scattering angles, although the variations are not terribly large when their magnitudes are compared to that of the forward scattering. For this particular model, it will be noted that AGAUSX convergence criterion led to its use of more radii than were used with the other codes. It will also be seen that MIE2 handled the 40 radii faster than did AGAUS9. MIE2's speed advantage over AGAUS9 probably results from the fact that MIE2 used non-uniform spacing of particle radii--a procedure which leads to a significantly smaller number of Mie calculations which must be done at large Mie size-parameters.

TABLE 5

COMPARISONS OF RESULTS AND CPU TIMES FOR THREE SINGLE SCATTERING CODES -

CLOUD MODEL C.1. ( $\lambda = 0.7\mu\text{m}$ )

Quantity	AGAUS9	AGAUSX (Delta-0.01)	MIE2	Deirmendjian T.36
$K_{\text{ext}} (\text{km}^{-1})$	16.7512	16.7223	16.780	16.73
$K_{\text{sca}} (\text{km}^{-1})$	16.7512	16.7223	16.780	16.73
Scattering Fractions				
$\theta$				
0°	2.2438E0	2.2404E0	2.2534E0	2.237E0
44°	1.952E-3	1.784E-3	1.0875E-3	
90°	6.1552E-5	4.8011E-5	5.6898E-5	
136°	1.8252E-4	1.9026E-4	2.1120E-4	
180°	8.9722E-4	8.3856E-4	8.9161E-4	8.457E-4
CPU Time (Seconds)	86.86	82.81	75.35	
No. of Radii	40	50	40	440

\*NOTE: AGAUS9 and AGAUSX scattering fractions at 0°, when converted to phase functions have values of 1683, as compares to Deirmendjian's values of 1680.

It should be noted that the version of AGAUSX used in generating results shown in table 5 performed its "convergence test" on the total aerosol volume and not on the scattering fractions. (Results obtained by checking on both volume and the scattered intensity at  $90^\circ$  will be given below.)

Although AGAUSX appears to offer no computation speed advantage if the user knows how many radii are "enough", it does have the useful feature (not found in either MIE2 or AGAUS9) of giving the user some idea of how many radii were really required to achieve some minimum level of confidence in its results.

By repeating runs of AGAUSX and model C.1 using various values of DELTA, it has been possible to learn more about the sensitivities of the extinction coefficient and scattering fractions to the number of radii used in a calculation. Table 6 contains the results of a few runs of that type. The first four entries represent runs in which the quantity which was tested for convergence was the total volume of the aerosol particles.\* The fifth and sixth entries are the results of runs in which testing was done on both volume and the scattered intensity at  $90^\circ$ ; note that the sixth entry represents a run at  $45^\circ$  increments rather than  $2^\circ$  increments.

Examination of table 6 shows that the value of the extinction coefficient is not nearly as sensitive to the choice of particle radius values as are the scattering fractions at fairly large scattering angles, especially near  $90^\circ$ . The  $90^\circ$  results show "oscillations" of as much as 15 percent as the number of radii changes through the set {26, 50, 66, 98, 130, and 513}.

It should also be noted that AGAUS9 and MIE2 runs shown in table 5 used only 40 radii, while Deirmendjian evidently used 440 radii. Even with that vastly larger number of radii, Deirmendjian's results are not so different from the present results to warrant, in many applications, an additional increase in computation time of a factor of eleven.

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\*Volume was used rather than extinction cross-section because its  $R^3$  dependence appeared to make it a "more sensitive" test quantity.

TABLE 6

## COMPARISON OF AGAUSX RESULTS OBTAINED WITH FOUR CONVERGENCE TEST LEVELS

USING CLOUD MODEL C.1. ( $\lambda = 0.7\mu\text{m}$ )

Convergence Level	NRADI	CPU (Seconds)	$K_{\text{ext}-1}$ ( $\text{km}^{-1}$ )	Scattering Fractions				
				0°	44°	90°	136°	180°
0.05	26	45.28	17.47	2.4521E0	1.1280E-4	5.2019E-5	1.8805E-4	7.4914E-4
0.01	50	82.81	16.72	2.2404E0	1.1784E-3	4.8011E-5	1.9026E-4	8.3856E-4
0.005	66	127.93	16.74	2.2395E0	1.1697E-3	5.6570E-5	1.9095E-4	8.7430E-4
0.001	130	245.13	16.73	2.2370E0	1.1815E-3	5.4473E-5	1.8960E-4	8.2393E-4
*0.05	98	220.91	16.73	2.2369E0	1.1814E-3	5.5012E-5	1.9213E-4	8.3975E-4
**0.005	513	143.73	16.75	2.2411E0		5.5880E-5		8.8647E-5

NOTES: (a) In these runs, the quantity which was tested for convergence was the total volume of the aerosol particles.

(b) In these runs, scattering fractions were calculated at 2° increments.

\*Special Version of AGAUSX with convergence checks on scattered intensity at 90° as well as on volume.

\*\*Similar to \* case, but only 5 angles used.

A similar set of comparative results obtained for cloud model C.3 are presented in table 7. For this model, AGAUS9 and MIE2 were run with the same number of radii as was used by Deirmendjian. This example illustrates the way in which AGAUSX can offer definite decreases in CPU time over codes requiring the user to make an a priori decision as to the number of radii needed. Using only 66 radii, AGAUSX produced an extinction coefficient to within better than 1 percent of Deirmendjian's value (with which AGAUS9 and MIE2 results are identical to the four digits given by Deirmendjian). AGAUSX, (with DELTA = 0.01), however, ran nearly four times faster than either AGAUS9 or MIE2. Furthermore, the AGAUSX run at DELTA = 0.01 yielded scattering fractions which, at worst, differed from those found by AGAUS9 and MIE2 by the order of 10 percent.

Cloud models such as C.1 and C.3 used at short wavelengths ( $\approx$  visible) are severe tests of single scattering codes because they typically involve some rather large Mie size-parameters ( $\alpha \approx 110$  for the C.1 model). Calculations performed at infrared wavelengths for smaller particles than found in typical clouds are not quite so demanding. That fact is illustrated partially, by tables 8 and 9, which were compiled using a hypothetical model for a hygroscopic smoke having the particle size-distribution of white phosphorous smoke. The model used here was denoted as model A' in an earlier document.<sup>7</sup> Table 8 shows extinction coefficients obtained from AGAUS9 (using 100 radii), and AGAUSX (using DELTA = 0.01) at seven different values of relative humidity. It also presents the results of a run of a special version of AGAUSX (labeled AGAUSXL) in which the Mie routine DOWN42 was used instead of routine MIEGX. It will be seen that AGAUSX (and AGAUSXL) needed only 34 radii to reach extinction coefficients within 0.2 percent of those found by AGAUS9, but the AGAUS9 run used 340 percent more computer time than did AGAUSX. AGAUSXL's results were quite close to those of AGAUSX, but the relative slowness of DOWN42 brought the total time to treat 34 radii up to nearly the same time needed by AGAUS9 to treat 100 radii.

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<sup>7</sup>A. Miller, R. C. Shirkey, E. Gemoets and G. H. Goedecke, 1978, Investigations on the Prediction of Infrared Transmission and Emission by Clear and Aerosol Laden Atmospheres, NMSU Department of Physics, Final Report for Contract DAEA18-77-C-00003

TABLE 7

COMPARISONS OF RESULTS AND CPU TIMES FOR THREE SINGLE SCATTERING CODES -

CLOUD MODEL C.3 ( $\lambda = 0.7\mu\text{m}$ )

Quantity	AGAUS9	AGAUSX*		MIE2	Deirmendjian T.60
		$\Delta = .01$	$\Delta = .001$		
$K_{\text{ext}} (\text{km}^{-1})$	3.0212	3.0078	3.0151	3.0218	3.021
$K_{\text{sca}} (\text{km}^{-1})$	3.0212	3.0078	3.0151	3.0218	3.021
Scattering Fractions*					
$\theta$					
0°	5.3970E-2	5.3569E-2	5.3796E-2	5.3946E-2	5.396
44°	2.1276E-4	2.1398E-4	2.1220E-4	2.1182E-4	
90°	2.0787E-5	2.1668E-5	2.2180E-5	2.0366E-5	
136°	3.5852E-5	3.2756E-5	3.4983E-5	3.5562E-5	
180°	2.0350E-4	1.7792E-4	1.9798E-4	2.0269E-4	1.64
CPU Time* (Seconds)	289.79	71.49	131.5	266.36	
No. of Radii	280	66	130	280	280

\*NOTES: (a) All runs calculated Scattering Fractions at 2° increments between 0° and 180°.

(b) The quantity tested for convergence was the total aerosol volume.

TABLE 8

COMPARISONS OF RESULTS FROM PROGRAMS AGAUS9 AND AGAUSX  
 FOR SMOKE MODEL A' AT  $\lambda = 10.6\mu\text{m}$  (Relative humidity = 0%)

Relative Humidity (percent)	AGAUS9 (100 radii)	Extinction Coefficients (per km)		%Difference*
		AGAUSX (34 radii)	AGAUSXL (34 radii)	
		[Delta - 0.01]		
0	0.1838	0.1835	0.1835	0.16
75	0.2801	0.2797	0.2797	0.18
80	0.3020	0.3016	0.3016	0.17
85	0.3340	0.3335	0.3335	0.27
90	0.3887	0.3882	0.3882	0.15
95	0.5350	0.5343	0.5343	0.15
99	1.9295	1.9268	1.9268	0.15
TOTAL CPU TIME	34.34 sec	9.83 sec	34.98 sec	71.4

\*NOTE: Percent differences are:  $\left| \frac{\text{AGAUS9} - \text{AGAUSX}}{\text{AGAUS9}} \right| \times 100$

TABLE 9

COMPARISON OF AGAUSX RESULTS FOR FOUR DIFFERENT CONVERGENCE LEVELS  
AND A SIMULATED SMOKE MODEL -  $\lambda = 10.6\mu\text{m}$  (Relative humidity = 0%)

Convergence Level (DELTA)	No. of Radii Used	$K_{\text{ext}}(\text{km}^{-1})$
.05	18	1.8277
.01	34	1.8353
.005	50	1.8345
.001	130	1.8377

Convergence Level (DELTA)	Scattering Fractions		
	$\theta = 0^\circ$	$\theta = 90^\circ$	$\theta = 180^\circ$
.05	1.5574E-6	6.9366E-7	1.2326E-6
.01	1.5610E-6	6.9555E-7	1.2365E-6
.005	1.5605E-6	6.9533E-7	1.2361E-6
.001	1.5621E-6	6.9613E-7	1.2376E-6



Table 9 demonstrates how the user's choice of DELTA affected runs of the simulated smoke model at a relative humidity of 0 percent. For that model, changes in the number of radii from 18 to 130 (a factor of seven) did not change either the extinction coefficient or the scattering fractions by more than 0.3 percent.

Discussion: One of the decisions which had to be made for program AGAUSX was that of determining just which "quantity" or set of quantities should be used in the test for convergence to within the level DELTA. The one which was finally chosen was the total volume of the aerosol particles. The volume was chosen because, being dependent on the cube of the radii, it might be a little more conservative choice than the extinction coefficient, although, as seen in tables 5 and 6, it is a less conservative test quantity than the scattered intensity at  $\theta = 90^\circ$ . Present experience is limited, but the use of the volume seems to be a good compromise unless highly precise scattering fractions are needed. If the latter situation arises in a particular application, users of the code should have no difficulty in coding in their own preferred test quantity. The quantities which are available at present are extinction, scattering, backscattering cross sections, and the average intensities at various angles. Careful study of the source listing for subroutine AGXPT2 will reveal how such changes can be made.

A major surprise which was revealed by these studies was the fact that the code MIE2 used less computer time to handle cloud models C.1 and C.3 than AGAUS9 needed (for the same number of radii). The reason for the surprise was that the basic Mie routine DOWN42 used by MIE2 was known to be usually appreciably slower than routine MIEGX. It was in fact, that difference in speed which caused AGAUSXL (see above, and table 8) to require more than three times as long to treat the smoke model than AGAUSX needed. The reason for MIE2's evident computation time advantage over AGAUS9 has been alluded to above, and appears to be the result of the differences in the ways in which the values of radii (at which the Mie calculations are to be done) are chosen in the two codes. In MIE2, the interval between successive values of particle radius is doubled as each additional value is assigned (at least for the generalized Khirgian-Mazin distribution), while AGAUS9 uses a constant increment. The MIE2 method therefore uses far fewer large values of radius

than the AGAUS9 method does. That difference, and the fact that the time required within the Mie subroutines DOWN42 and MIEGX increases rapidly with the size to wavelength ratio, appears to account for MIE2's (small) running time advantage over AGAUS9. That difference in how the radii are chosen definitely accounts for the disagreements between the MIE2 and AGAUS9 values for the scattering fractions for cloud models C.1 and C.3 (that disagreement is quite appreciable in table 5 in some cases). The latter conclusion has been verified by direct runs with a version of AGAUS9 which uses the MIE2 method for choosing the radii (the AGAUS9/MIE2 disagreements moved out to the fifth or sixth digit). The running time on a UNIVAC 1108 of the special version of AGAUS9 was 240 seconds as compared to 266 seconds for MIE2, demonstrating that the use of fewer large radii significantly decreases running time.

The questions raised above are, however, made somewhat academic by AGAUSX for many applications requiring single scattering calculations because of AGAUSX's clear speed advantage in handling distributions for which no a priori guide as to how many radii will be "enough" is available.

#### SOME EFFECTS OF THE NUMER OF SIZE INTERVALS USED IN AGAUSX

In the early development of AGAUSX, it was tentatively assumed that computation times might be substantially reduced by breaking the total ranges of radius values to be treated into more than one "size-interval" and then performing the halving calculations and tests separately within each size interval. That assumption was based upon the belief that the use of a single interval could result in unneeded computations in some size ranges brought about by slow convergence in other ranges. Consequently, all types of distribution functions which were known to be "peaked" were split into two size intervals: (a) one with radii smaller than the one at which the distribution was a maximum, and (b) one containing all larger values of particle radii. In some of the test runs, however, it was found that the interval containing the smaller radii required more halvings than the other interval, but contributed only a small fraction of the total extinction effects--thereby wasting computation time.

The effect of using just a single size interval, instead of two intervals, has been briefly explored using a special version of AGAUSX, and Deirmendjian's cloud models C.1 and C.3 at  $\lambda = 0.7\mu\text{m}$ . Computations were made with several different values for the convergence level ( $\Delta$ ). Table 10 compares some of the results found with the special version (AGAUS10S) and the regular version. The scattering fraction computations were made at  $2^\circ$  increments in most cases shown in the table, and the column labeled "NI" explicitly shows the number of size intervals used. Also shown and labeled "REF CASE", are the results obtained with an AGAUSX run which used all 513 available values of particle radii.

The results seen in table 10 indicate that the special version (AGAUS10S) required only one-third to one-half as much computation time to satisfy the different convergence levels as AGAUSX needed. It thus appears that the initial assumption that two intervals would be preferable to one interval may be false. However, a closer examination of the table shows that AGAUS10S yielded substantially large scattering fractions (away from  $0^\circ$ ) than did AGAUSX, with the latter code's values being closer to the "REF CASE" values at all choices of  $\Delta$ .

About the only conclusions which can be drawn at this point are that the NI = 1 version is by far the most efficient when only  $k_{\text{ext}}$  is of interest, and that the NI = 2 version is preferable, in spite of its slower speed, if high accuracies are needed for the scattering fractions at large scattering angles. From another vantage point, however, the discrepancies between the NI = 1 and NI = 2 scattering fractions at  $\theta = 90^\circ$  and  $\theta = 180^\circ$  are an insignificant fraction of the  $\theta = 0$  values.

A few similar comparisons for Deirmendjian's cloud model C.3 at  $\lambda = 0.7\mu\text{m}$  are given in table 11.

Comparison of Results for the Analytic Phase Functions: Two models have been chosen to compare the two analytic phase functions, Henyey-Greenstein and Goedecke-Henyey-Greenstein with the 'true' or computed phase function. These models and selected wavelengths at which comparisons were made are: simulated

TABLE 10

COMPARISON OF RESULTS PRODUCED FOR CLOUD MODEL C.1 ( $\lambda = 0.7\mu\text{m}$ )  
 BY SEVERAL VARIANTS OF PROGRAM AGAUSX AND DIFFERENT CONVERGENCE LEVELS ( $\Delta$ )

DELTA	*	NI	NRADI	$K_{\text{ext}}$	CPU	Scattering Fractions		
						0°	90°	180°
0.05	a	2	26	17.47	45.28	2.4521	5.2019E-5	7.4914E-4
	b	1	9	16.70	21.06	2.2353	6.9736E-5	1.29463-3
	c	1	9	16.70	note-d	2.2353	6.9736E-5	1.2946E-3
0.01	a	2	50	16.72	82.81	2.2404	4.8011E-5	8.3856E-4
	b	1	17	16.77	38.72	2.2438	7.0311E-5	1.0222E-3
	c	1	129	16.74	note-d	2.2386	5.6969E-5	9.1422E-3
0.005	a	2	66	16.74	127.93	2.2395	5.6570E-5	8.7430E-4
	b	1	17	16.77	37.78	2.2438	7.0311E-5	1.0222E-3
0.001	a	2	130	16.73	245.13	2.2370	5.4473E-5	8.2393E-4
	b	1	33	16.76	75.71	2.2398	6.8529E-5	9.3237E-4
"Reference Case"	c	2	513	16.75	note-d	2.2411	5.5880E-5	8.8647E-4
Deirmendjian		1	440	16.73		2.2370		8.457E-4

- \*NOTES: (a) "Normal" AGAUSX convergence tests on aerosol volume; 2 size intervals.  
 (b) AGAUS10S; convergence tests on extinction coefficient; 1 size interval.  
 (c) AGAUS10S; convergence tests on extinction coefficient and scattered intensity at  $\theta = 90^\circ$ ; number of size intervals given in column labeled "NI".  
 (d)  $45^\circ$  angular increment runs; CPU times not directly comparable to other runs made at  $2^\circ$  increments.

TABLE 11

COMPARISON OF AGAUSX RESULTS FOR CLOUD MODEL C.3 ( $\lambda = 0.7\mu\text{m}$ ) USING ONE AND TWO SIZE INTERVALS, SEVERAL CONVERGENCE LEVELS AND CONVERGENCE TESTS ON EXTINCTION COEFFICIENT AND SCATTERING FRACTIONS AT  $90^\circ$

DELTA	NI	NRADI	$K_{\text{ext}}$	CPU <sup>(a)</sup>	Scattering Fractions		
					$0^\circ$	$90^\circ$	$180^\circ$
0.1	--	--	--	--	--	--	--
	1	33	3.042	34.81	5.4626E-2	2.2433E-5	2.5350E-4
0.05	--	--	--	--	--	--	--
	1	65	3.041	68.71	5.4583E-2	2.2435E-5	2.3498E-4
0.01	2	66	3.008	71.49	5.3569E-5	2.1668E-5	1.7792E-4
	1	65	3.041	72.67	5.4583D-2	2.2435E-5	2.3498E-4
0.005	--	--	--	--	--	--	--
	1	65	3.041	72.06	5.4583E-2	2.2435E-5	2.3498E-4
0.001	2	130	3.015		5.3796E-2	2.2180E-5	1.9798E-4
	1	129	3.041	16.86 <sup>b</sup>	5.4585E-2	2.1382E-5	2.3500E-4
.0001	1	513	3.021	62.83 <sup>b</sup>	5.3985E-2	2.0643E-5	2.0382E-4
Deirmendjian	280		3.021		5.396E-2	--	2.025E-4

NOTES: (a) CPU times in seconds, using  $2^\circ$  angular increments.

(b) Not comparable to other runs due to use of  $45^\circ$  increments.

(c) Cases for which dashes (---) appear were not run for NI=2 and convergence tests on both  $K_{\text{ext}}$  and the scattered intensity at  $\theta = 90^\circ$ .

white phosphorus<sup>7</sup> at 1.06 and 10.6 microns; fog model WSMRF2 at wavelengths of 2.5, 10.0 and 11.0 microns; the parameters for each of the two fog models are tabulated below.

WSMRF2	
Radius, Minimum	0.4 $\mu$ m
Radius, Maximum	12.0 $\mu$ m
Radius, Mode	4.0 $\mu$ m
Alpha	6.0
Gamma	1.0
Particle Density	100.0cm <sup>-3</sup>

Values of the analytical phase functions HG and GHG, along with the computed phase functions are presented graphically in figures 1 through 5. A visual inspection of these figures shows that the GHG analytic phase function matches the computed phase function far better than the HG phase function near zero degrees, and that the GHG function apparently provides a better overall fit to the computed phase function than the HG function. Because the scales of the graphs usually do not permit sufficient resolution near 180°, the values of the computed and analytic phase functions are presented in table 12 at selected angles. Table 12 also presents the differences between the computed and analytic phase functions at the selected angles, and also the root mean square error for the points considered.

Discussion: Inspection of table 12 shows that the GHG analytic phase function is superior to the HG analytic phase function at angles near zero degrees.

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<sup>7</sup>A. Miller, R. C. Shirkey, E. Gemoets and G. H. Goedecke, 1978, Investigations on the Prediction of Infrared Transmission and Emission by Clear and Aerosol Laden Atmospheres, NMSU Department of Physics, Final Report for Contract DAEA18-77-C-00003

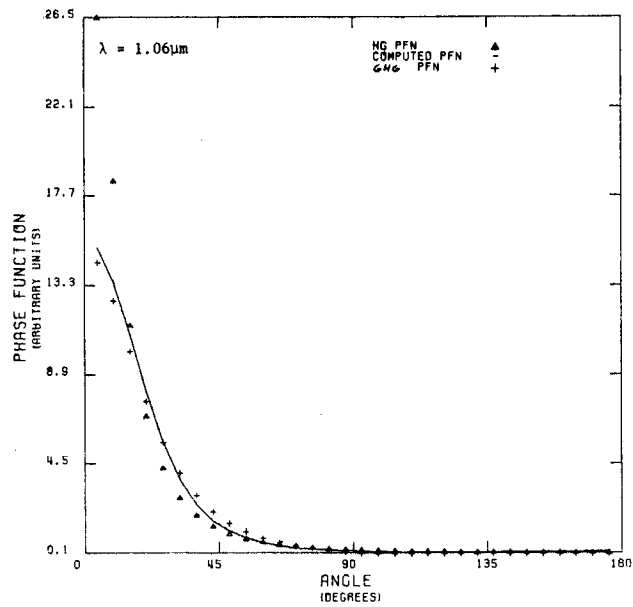


Figure 1. Comparison of analytic phase functions HG and GHG with computed phase function for simulated white phosphorous at  $1.06 \mu\text{m}$ .

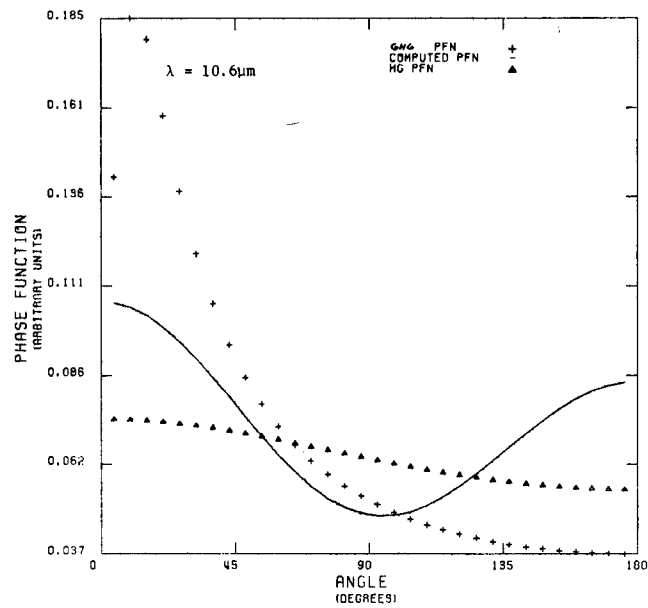


Figure 2. Comparison of analytic phase functions HG and GHG with computed phase function for simulated white phosphorous at  $10.6 \mu\text{m}$ .

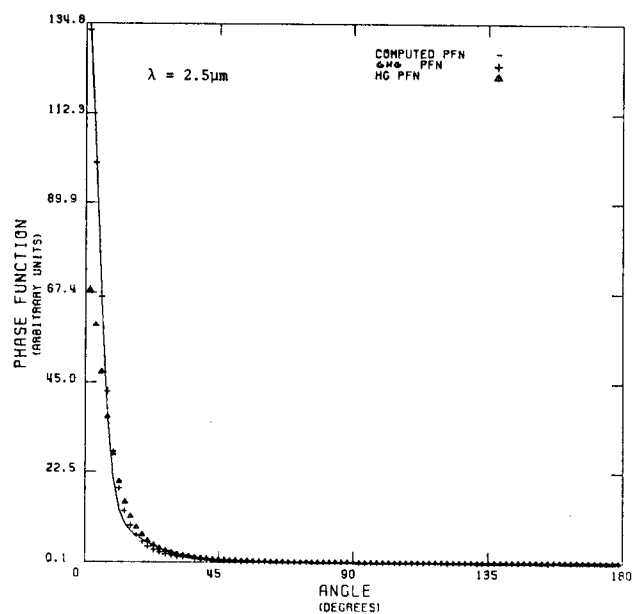


Figure 3. Comparison of analytic phase functions HG and GHG with computed phase functions for fog model WSMRF2 at  $2.5\mu\text{m}$ .

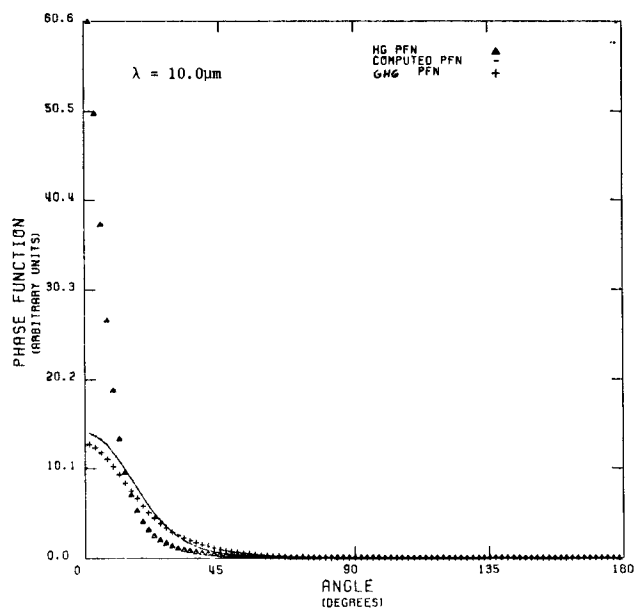


Figure 4. Comparison of analytic phase functions HG and GHG with computed phase functions for fog model WSMRF2 at  $10.0\mu\text{m}$ .



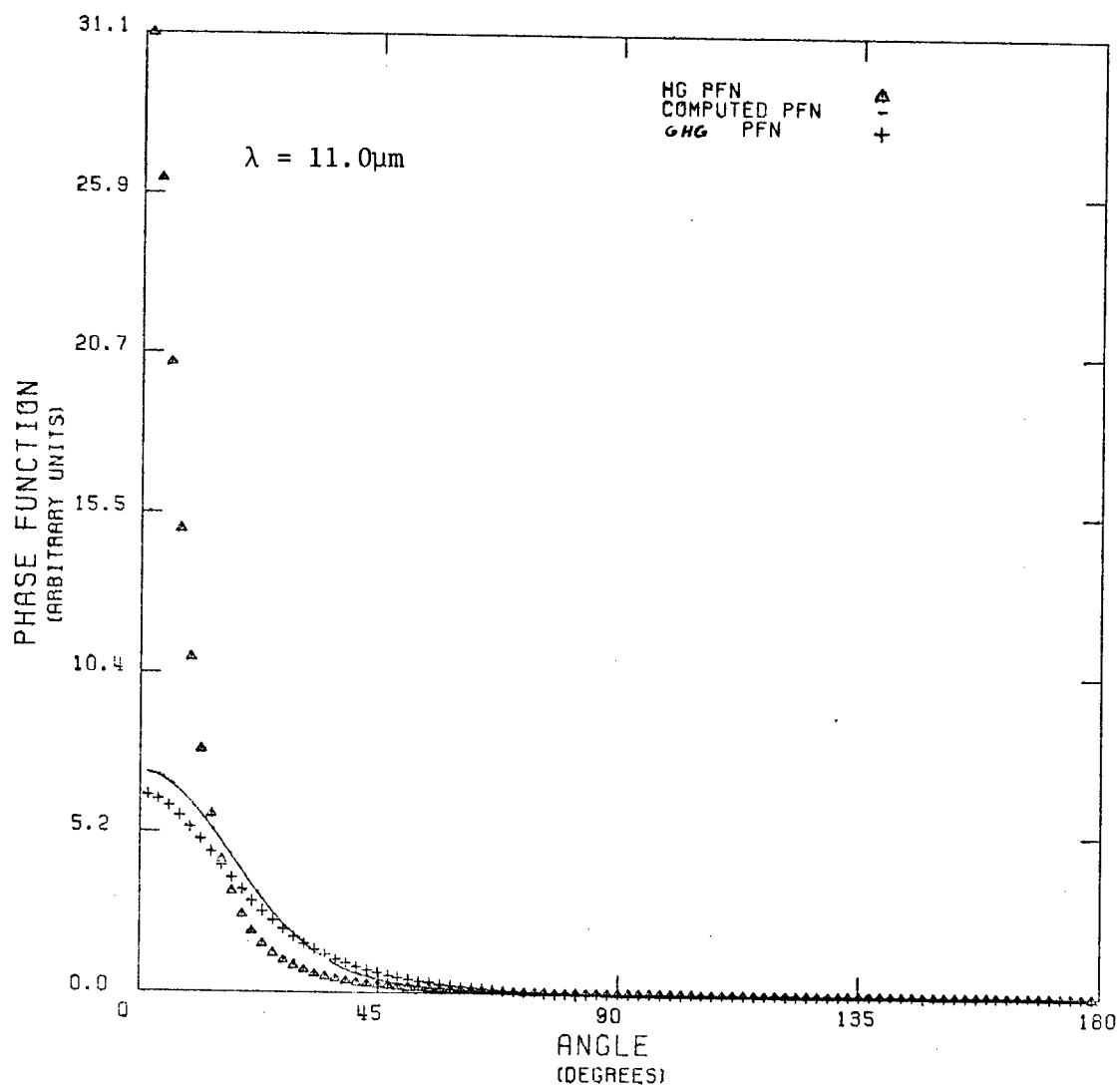


Figure 5. Comparison of analytic phase functions HG and GHG with computed phase function for fog model WSMRF2 at  $11.0\mu\text{m}$ .

TABLE 12

COMPARISON OF COMPUTED AND ANALYTIC PHASE FUNCTION VALUES AT SELECTED ANGLES FOR  
FOG MODEL WSMRF2 AND SIMULATED WHITE PHOSPHOROUS AT VARIOUS WAVELENGTHS

Wavelength		Model WSMR F2			
2.5 $\mu$ m		Phase Function Values*			
Angle( $^{\circ}$ )	True $\dagger$	HG	HG-GG	$\Delta_1^+$	$\Delta_2^+$
1.51	134.80	68.17	133.20	66.63	1.60
25.08	3.59	3.56	2.56	.03	1.30
50.66	.49	.55	.43	-.06	.06
74.26	.13	.20	.18	-.07	-.05
99.84	.06	.10	.11	-.04	-.05
125.41	.09	.06	.08	.03	.02
150.98	.09	.05	.07	.04	.02
174.58	.17	.05	.07	.12	.10
178.49	.23	.05	.07	.18	.16
				22.21	.64

Wavelength		Model WSMR F2			
10.0 $\mu$ m		Phase Function Values*			
1.51	14.12	60.63	12.86	-46.51	1.26
25.08	4.32	2.07	3.97	2.25	.35
50.66	.38	.30	.68	.08	-.30
74.26	.08	.11	.09	-.03	-.01
99.84	.03	.05	.00	-.02	.03
125.41	.02	.04	.00	-.02	.02
150.98	.02	.03	.00	-.01	.02
174.58	.02	.02	.00	.00	.02
178.49	.02	.02	.00	.00	.02
				15.52	.45

Table 12 (cont)

Wavelength 11.0 $\mu$ m Angle( $^{\circ}$ )	Model WSMR F2				
	True $^{\dagger}$	HG	HG-GG	$\Delta_1^+$	$\Delta_2^+$
1.51	7.14	31.08	6.39	-23.94	.75
25.08	2.61	1.28	2.34	1.33	.27
50.66	.26	.19	.45	.07	-.19
74.26	.05	.07	.07	-.02	.00
99.84	.02	.03	.01	-.01	.01
125.41	.01	.02	.01	-.01	.00
150.98	.01	.02	.01	-.01	.00
174.58	.01	.02	.01	-.01	.00
178.49	.01	.02	.01	-.01	.00
				7.99	.27

Wavelength 1.06 and 10.6 $\mu$ m	Model WP (1.06 $\mu$ m)			Model WP (10.6 $\mu$ m)		
	Phase Function Values*			Phase Function Values*		
4.24	15.15	26.52	14.40	-11.37	.75	.14
26.32	5.58	4.26	5.55	1.32	.03	.14
48.47	1.15	1.00	1.53	.15	-.38	.09
76.16	.26	.32	.29	-.08	-.03	.06
98.30	.13	.18	.02	-.05	.11	.05
126.00	.10	.11	.02	-.01	.08	.04
148.14	.12	.09	.02	.03	.10	.04
175.76	.17	.08	.02	.09	.15	.04
RMS# =				4.05	.31	.02
						.03

\*Rounded to two decimal points

 $^{\dagger}$ Computed via Mie Theory

#True minus analytic: 1 = Henyey-Greenstein; 2 = modified Henyey-Greenstein.

#RMS = Root Mean Square

However, as one approaches  $180^\circ$  the HG function sometimes provides a better fit to the computed phase function. Since for most of the distributions examined the backscatter is far less than the forward scattering, it becomes important to analytically fit the computed phase function more closely near the forward direction of scattering relative to the backscatter direction. Additionally since the HG analytic function fits the computed phase function best near  $180^\circ$  and the GHG analytic function is partially comprised of the HG function near  $180^\circ$ , we again find that the GHG analytic function will fit well near  $180^\circ$ . The root mean square error is also presented for the difference between the computed and analytic phase functions, and again indicates that the GHG analytic phase function provides a better fit. This is particularly so if the particular regime under consideration is near the incident (forward) direction.

#### STUDIES OF IR EXTINCTION IN HYGROSCOPIC AEROSOLS

Introduction: In a previous document<sup>7</sup> some results of the modeling of IR extinction in hygroscopic aerosols were reported. Since then additional computations have been made to extend the range of relative humidities beyond that used previously and to examine the effects of "hysteresis" in the condensation and evaporation of droplets formed upon hygroscopic condensation nuclei. The new calculations were carried out using the simulated white phosphorous smoke model A' defined in the report referenced above.

Computations were carried out with an early version of program AGAUS9 at wavelengths of 0.55, 1.06, and  $3.6\mu\text{m}$ . Twelve values of relative humidity were used, and mass accretion coefficients were taken from Hanel<sup>8</sup> for conditions of

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<sup>7</sup>A. Miller, R. C. Shirkey, E. Gemoets and G. H. Goedecke, 1978, Investigations on the Prediction of Infrared Transmission and Emission by Clear and Aerosol Laden Atmospheres, NMSU Department of Physics, Final Report for Contract DAEA18-77-C-00003

<sup>8</sup>G. Hanel, 1976, "The Properties of Atmosphere Particles as Functions of the Relative Humidity at Thermodynamic Equilibrium with the Surrounding Moist Air," Advan Geophys, Editors H. E. Landsberg and J. Van Mieghem, Academic Press, New York

Results: The data generated by the new computations are presented in graphical form in figures 6 through 8. Figure 6 shows the absolute extinction coefficients as a function of relative humidity at  $\lambda = 0.55\mu\text{m}$  and  $\lambda = 1.06\mu\text{m}$ . The arrowheads indicate the direction in which relative humidity is changing; an arrowhead tilted toward the right represents increasing relative humidity, and an arrowhead tilted toward the left represents decreasing relative humidity. Figure 6 clearly shows the "hysteresis" effect mentioned above. It will be seen that for relative humidities between about 60 and 75 percent, the value of the extinction coefficient may vary by a factor of two between conditions of rising and falling relative humidity. For both wavelengths shown, figure 6 can be interpreted as suggesting that clearing (associated with droplet evaporation) of a smoke cloud under conditions of decreasing relative humidity is slower than its formation at any given relative humidity between about 50 and 75 percent. The figure also demonstrates that the sense of changes in relative humidity may be as important as its value in modeling hygroscopic aerosols.

In figure 7 one will find graphs of the ratios of the extinction coefficients at  $1.06\mu\text{m}$  and  $3.56\mu\text{m}$  to those at  $0.55\mu\text{m}$  as a function of relative humidity, figure 7 is subject to various interpretations. One inference is that the aerosol model used for these calculations is almost always (all relative humidities = 99 percent) more "transparent" at  $3.56\mu\text{m}$  than at  $0.55\mu\text{m}$ , but the same statement cannot be made at  $1.06\mu\text{m}$ . This particular aerosol, while more transparent at  $10.6\mu\text{m}$  than at  $0.55\mu\text{m}$  for relative humidities below about 59 percent, is comparatively less transparent for larger saturation ratios. Other features discernable from figure 7 are that extinction at  $1.06\mu\text{m}$  as compared to its value at  $0.55\mu\text{m}$  is much less sensitive to relative humidity than it is for  $3.56\mu\text{m}$  radiation. In other words, the extinction at  $1.06\mu\text{m}$  can be predicted more accurately from knowledge of the extinction at  $0.55\mu\text{m}$  than can be the extinction at  $3.56\mu\text{m}$  when no information on relative humidity is available. One further obvious inference from figure 7 is that extinction at  $1.06\mu\text{m}$  will be greater than at  $0.55\mu\text{m}$  if the smoke cloud is clearing because of decreasing relative humidity.

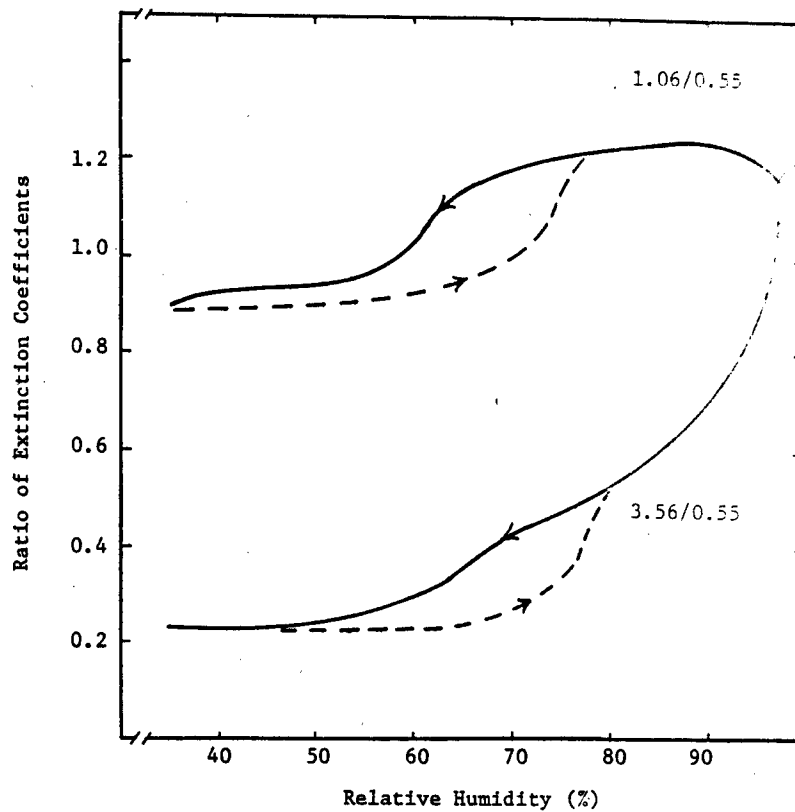


Figure 6. Computed extinction coefficients for smoke model A' as a function of relative humidity;  $\lambda$  is the wavelength in  $\mu\text{m}$ . The solid curves and broken curves represent conditions of decreasing and increasing relative humidity, respectively.

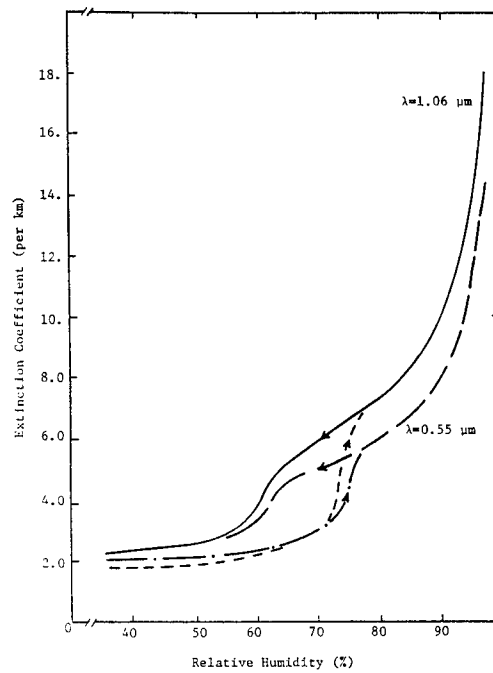


Figure 7. Ratio of Model A' extinction coefficients at  $\lambda = 1.06\mu\text{m}$  and  $\lambda = 3.56\mu\text{m}$  to values at  $\lambda = 0.55\mu\text{m}$  as a function of relative humidity. The solid curves represent increasing relative humidity, and the dashed curves represent decreasing relative humidity.

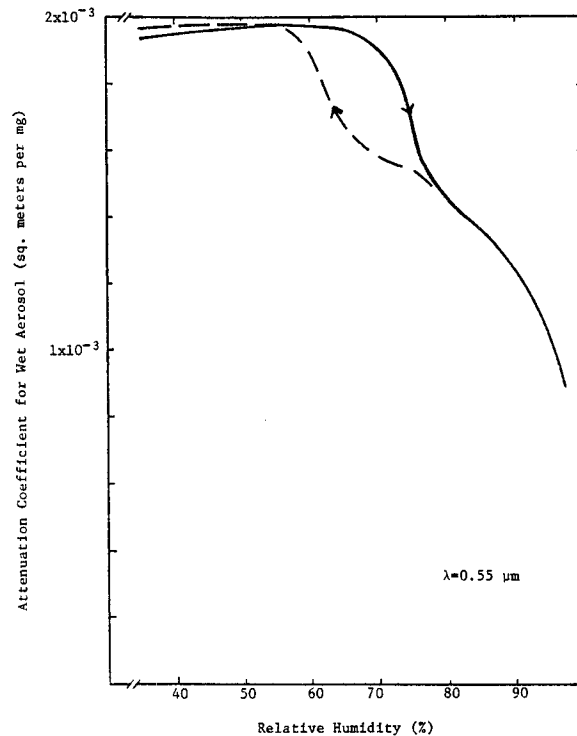


Figure 8. Attenuation coefficient per unit mass of Wet Aerosol at  $0.55\mu\text{m}$  versus Relative Humidity for smoke model A'. The solid curve is for increasing relative humidity and the dashed curves represent decreasing relative humidity.

Finally, figure 8 shows the attenuation coefficient per unit mass of WET aerosol at  $\lambda = 0.55\mu\text{m}$  as a function of relative humidity. If that figure is compared with figure 6, it will be seen that the attenuation per unit mass of the existing aerosol (WET + nuclei + accreted water) is much less sensitive to relative humidity than the attenuation per unit mass of dry aerosol material. It suggests that simultaneous in situ measurements of aerosol mass concentrations and extinction which preserve accreted water should yield less uncertainty or variation in extinction with changes in relative humidity than measurements made on dry aerosol materials alone.

Discussion: The results described above can, of course, be applied in detail only to the aerosol model used in generating them and at the specific wavelengths used. They do suggest, however, that extinction can, under some situations at least, vary by nearly a factor of two at a given relative humidity between conditions of rising and falling relative humidity, and that the relationship between extinction at two different wavelengths may also be dependent on the direction of changes in relative humidity. Consequently, it would seem that persons involved in both field measurements and numerical modeling should pay considerable attention to meteorological conditions, in particular when the relative humidity is rising or falling.

#### FURTHER DESCRIPTION OF THE "HALVING" METHODS OF AGAUSX

Basic Concept. A general idea of how program AGAUSX operates can be obtained by considering a numerical method for determining the area under a curve  $g(R)$  versus  $R$  such as that sketched in figure 9. The objective is to evaluate numerically an integral

$$G = \int_{R=0}^{R=\infty} g(R) dR \quad (61)$$

to some desired degree of accuracy using the smallest number of values of  $R$  for the numerical calculations. The procedure adopted in AGAUSX is as follows (reference to figure 9 may be helpful):



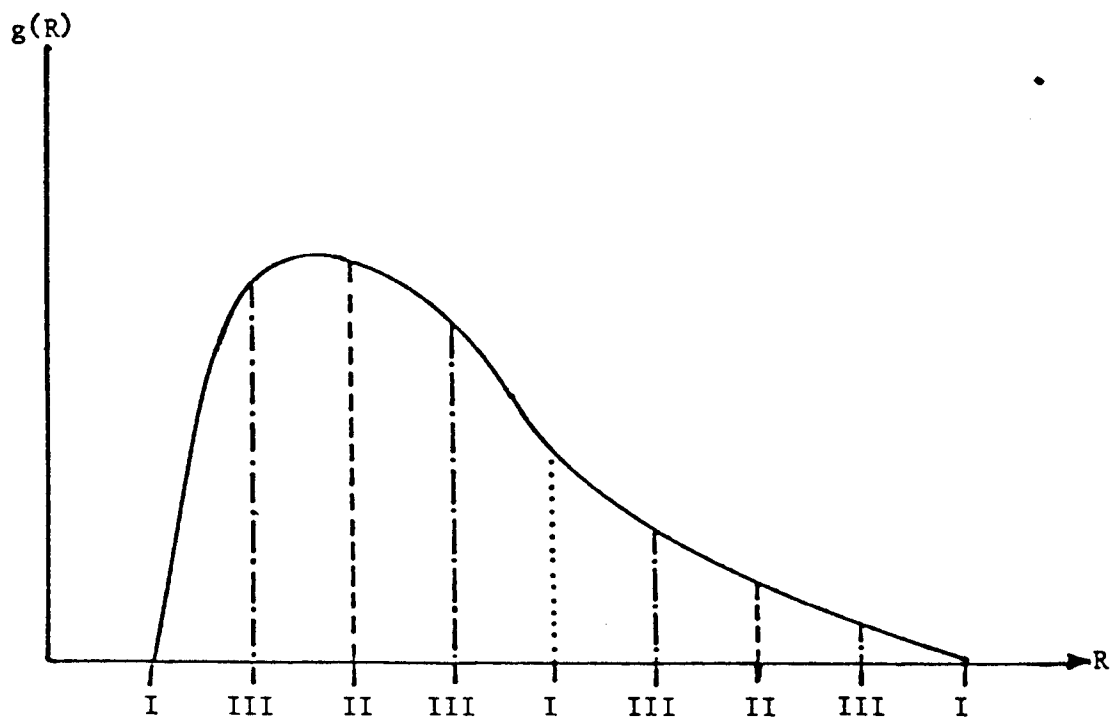


Figure 9. Sketch of how values of particle radii are selected in the halving procedure of AGAUSX.

(1) An initial estimate  $G_1$  of the value of the integral is made using three values of  $R$  labeled by Roman numeral I and the "trapezoidal rule".

(2) A second estimate  $G_2$  is then made using increments  $\Delta R$  which are half as large as those used in getting  $G_1$ . In getting  $G_2$ , the two additional  $R$ -values labeled II are utilized.

(3) The values of  $G_2$  and  $G_1$  are compared to each other by calculating a quantity

$$\delta = \frac{|G_2 - G_1|}{|G_2|} \quad (62)$$

and comparing it to a pre-set quantity  $\Delta$ .

If  $\delta < \Delta$ , then it is assumed that  $G_2$  is a "sufficiently" accurate representation of  $G$ , and the computations are terminated. If on the other hand,  $\delta > \Delta$ , one proceeds.

(4) A third estimate  $G_3$  of  $G$  is then made by again cutting the increments  $\Delta R$  to half its previous value. This results in the addition of computations at the four new  $R$ -values labeled III in figure 9. A new value of  $\delta$  is then calculated from

$$\delta = \frac{|G_3 - G_2|}{G_3}, \quad (63)$$

and  $\delta$  is again compared to  $\Delta$ . If  $\delta$  is still greater than  $\Delta$ , the spacing between R-values is cut in half once more, and the "estimation-comparison" process is repeated until either (a)  $\delta < \Delta$ , or (b) some maximum number of R-values has been reached.

In AGAUSX, the quantity used in the testing process is the total volume of the aerosol particles, namely,

$$V = \int \frac{4}{3} \pi R^3 f(R) dR, \quad (64)$$

in which  $f(R)dR$  is the relative number of aerosol particles whose radii lie between R and  $R+dR$ .

Extensions to the Basic Concept: It may happen that the function  $g(R)$  illustrated in figure 6 will have a form which is much "smoother" over some range of R-values than over other ranges. Strict application of the halving procedure to such a situation could easily lead to the use of many more R-values in one of those ranges than are really needed because of behavior of  $g(R)$  in other R-ranges. Such a situation seems especially likely with asymmetric size-distributions. One way of attempting to avoid unneeded computations in various R-ranges is to split the regions used in halving loops into several distinctive "intervals"-- $R_A$  to  $R_B$ ,  $R_B$  to  $R_C$ ,  $R_C$  to  $R_D$ , and to do the halving operations and convergence tests separately for each "interval." AGAUSX has been coded to permit separate halving computations and convergence testing for up to eight "intervals" of that type. In fact, the present coding uses two radius "intervals" (ranges) for those distributions  $f(R)$  known to show a single maximum, four "intervals" for bi-modal distribution models, and just one interval for other models.

## DETAILED DESCRIPTION OF PROGRAM AGAUSX

Program AGAUSX is designed to calculate various light-scattering quantities such as phase functions (Mie theory), scattering fractions (ACT), extinction cross-section, attenuation coefficient, etc., for diverse natural and artificially created polydisperse atmospheric aerosols. The program consists of subroutines ANGLE, GUSET, AGXPT1, AGXPT2, AGXPT3, AGXPRT, MIEGS, GAUS, VERFY, WATER, GPHASX, GUSSTX, and PRINTX. The organization and operation of these subroutines is controlled by the MAIN program AGAUSX. Additionally program AGAUSX will produce an analytic (GHG) phase function if the user desires.

### MAIN PROGRAM AGAUSX

The first input card contains the parameters NWAVE, NINDX, IDSTP, NRADI, IT, IANG, NCRDS, ITOT, NUNIT, MQRTE, and IAPX. These parameters will be explained in detail subsequently. The various modes of operation of AGAUSX that are possible, are controlled by some of these parameters. If IANG = 0, the subroutine GUSET is called to choose 'IT' scattering angles between  $0^\circ$  and  $180^\circ$  for use in numerical integrations using Gauss-Legendre quadrature. GUSET returns two arrays of numbers to MAIN. The array C(I) corresponds to the cosine of scattering angles and the array H(I) corresponds to the quadrature weights.

If IANG = 1 or 2, all the calculations of the previous paragraph are skipped. Instead subroutine ANGLE is called and returns arrays C(I) and H(I) to MAIN. For IANG = 1, H(I) corresponds to 'IT' equally spaced angles between  $0^\circ$  and  $180^\circ$ , and C(I) corresponds to the cosine of these angles. If IANG = 2, 'IT' user supplied angles are read in, again with H(I) corresponding to 'IT' angles and C(I) their cosines.

If IAPX is greater than zero AGAUSX will operate in a special 'approximation' mode. That is AGAUSX will construct the GHG analytic phase function at IAPX Gauss-Legendre angles. When approximate, quick phase functions are desired, this mode should be used.

Next, subroutine AGXPT1 is called. One or more input parameters are read at this point depending on the value of IDSTP, which indicates the type of distribution to be used. AGXPT1 calculates and returns two arrays R(I) and F(I) which describe the normalized size distribution, and VOL, the average 'dry' volume per particle. The array R(I) contains values of 'NRADI' particle radii, and the array F(I) contains values of the distribution for the corresponding R(I). For IDSTP = 3, 7, 8, 9, 10, 11, or 12 AGXPT1 also returns DENS, the particle number density (per  $\text{cm}^3$ ). For other distribution types that do not have predetermined density values, the user supplied density, DENS<sub>H</sub>, is less than  $10^{-4}$ ; in this case the particle number density will be calculated from mass densities and mass concentrations.

The parameters WAVE, DWAVE, RELHUM, DENS<sub>H</sub>, TEMP and DELTA are read next. The next do-loop indexed by N<sub>WAVE</sub> allows computations at several wavelengths during a single run. An additional looping option is available by assigning DWAVE any value less than  $10^{-4}$ ; the same do-loop is used to handle several values or relative humidity (RELHUM) in a run.

A switch parameter LLLL is assigned a value 0 or 1, in a manner dependent upon the value of IDSTP and DENS<sub>H</sub>. That is if the chosen distribution has fixed parameters and/or if number densities are to be calculated later from the average particle volume, mass density and mass concentration, then LLLL = 1.

In subroutine AGXPT2 optical and physical data (index of refraction and mass density) for the aerosol material are read. For the user's convenience, subroutine WATER has been added to provide the relevant data for water limited to the range 0.2 to 200 micrometers. If RELHUM and the growth factor (EMUA) are non-zero, AGXPT2 takes into account the particle growth and the change in density and indices of refraction of the aerosol material due to the absorption of water.

In AGXPT2, subroutine MIEGX is called for each 'adjusted' radius. MIEGX returns to AGXPT2 the values of extinction, scattering and backscattering

efficiency factors, and the average intensity factors  $(I_1 + I_2)/2$  for the 'IT' scattering angles chosen earlier. These scattering functions are weighted and integrated over the size distribution.

If the aerosol is a mixture of components having different physical and/or optical properties, the above calculation is repeated for each component and various functions are summed over NINDEX (the number of components). In the end AGXPT2 returns to MAIN, for each wavelength, the average (sum/total particle number density) extinction, scattering and back-scattering cross-sections (CTSUM, CSSUM, CRSUM), the average intensities (P(J)), and the total mass concentration (TMASS, in gm/cc, which includes the mass of any liquid water absorbed by hygroscopic aerosols).

The next subroutine is called AGXPT3. AGXPT3 uses the numbers received from AGXPT2 and returns to MAIN the total extinction, scattering, and back-scattering coefficients, scattering fractions and phase functions. AGXPT3 also calculates the albedo for single scattering "ALBDO" =  $\tilde{\omega}_0 = C_{\text{sca}}/C_{\text{ext}}$  and prints out all the single wavelength results. Later in AGXPT3, If IANG = 0, subroutine GAUS is called. Using the quadrature weights H(I) calculated earlier and calculating the Legendre polynomials PL(,), GAUS generates the Legendre expansion coefficients  $\tilde{\omega}_\ell$  for the phase functions, and places them in array OL(I). The  $\tilde{\omega}_\ell$ 's are then used to reconstruct phase functions, PC(I): GAUSS computes the root mean square deviation between the original phase functions and the reconstructed phase functions. If IANG = 1, the above calculation is skipped.

If NWAVER > 1, all the calculations of AGXPT2 and AGXPT3 are repeated (NWAVER-1) additional times. In MAIN, various scattering functions are summed and divided by NWAVER, and subroutine AGXPRT is called to print out all the averaged results. AGXPRT also calls GAUS once more (if IANG = 0) to generate the coefficients  $\tilde{\omega}_\ell$  for the averaged phase functions.

If IAPX is greater than zero, subroutine GPHASX is called to construct an analytic phase function, hereafter referred to as the GHG phase function. This requires the additional subroutines, GPHASX, GUSSTX, and PRINTX. This routine will construct the GHG analytic phase function at IAPX Gauss-Legendre

angles, and the subsequent Legendre coefficients may be written/punched on a unit specified by NUNIT if the user so desires.

#### Explanation of Symbols used in AGAUSX (MAIN)

<u>SYMBOL</u>	<u>Explanation or Definition</u>
ALBDO	single scattering albedo.
AMAX	the largest Mie size found in the aerosol distribution.
C( )	array holding cosines.
CATTN	the average (sum/NWAVE) attenuation coefficient in square meters per milligram of aerosol material.
CRSUM	the back-scattering cross-section in square micrometers for each wavelength and integrated over size distribution. AGXPT3 returns !coefficients!.
CSSUM	the scattering cross-section in square micrometers for each wavelength and integrated over size distribution. AGXPT3 returns 'coefficients'.
CTSUM	the extinction cross-section in square micrometers for each wavelength and integrated over size distribution. AGXPT3 returns 'coefficients'.
DELTA	convergence criterion.
DENS	the particle number density (number per cubic centimeter). The value of DENS may be supplied by the user as an input parameter, DENSH. However, it will be ignored when IDSTP = 0 or greater than 6, because these distribution types carry predetermined values of DENS. In the case of IDSTP = 1, 2, 4, 5, the user supplied value of number density

will be ignored only if it less than  $10^{-4}$ . In such cases DENS is calculated from mass density and concentration and average volume per particle, and is represented by DENSC.

DENSH	the user-supplied particle number density; units are particles per cubic centimeter. See discussion of DENS (above).
DRYVOL	the average volume per particle of dry aerosol in cubic micrometers.
DWAVE	the wavelength increment in micrometers, or relative humidity looping indicator.
ELWC	the liquid water content in $\text{gm/cm}^3$ (used only for cases IDSTP = 6 and 12).
EMM	the refractive index of the surrounding medium.
ENWAV	DFLOAT (NWAVE).
FSUM	the numerical result for the integral over the size distribution function with respect to radius; it is used to normalize the distribution function to one (equivalent) particle per cubic centimeter.
GNU	wave number in $\text{cm}^{-1}$ .
H( )	array containing angles.
LANG	= 0, for the computation of phase functions at 'IT' Gauss-Legendre quadrature angles.



IANG            = 1, for computation of phase functions and scattering fractions at 'IT' equally spaced angles between  $0^\circ$  and  $180^\circ$  . = 2, for computation of phase functions and scattering fractions at 'IT' user supplied angles.

IDSTP          identified the type of aerosol size distribution to be used. It can only take values between 0 and 12. See AGXPT1 for more details.

IAPX           the order of Legendre expression for the analytic, GHG, phase function expansion when IAPX is greater than zero.

IDBLE          single or double precision mode industor.

IT             the order of Legendre expansion for phase functions when IANG = 0, or the number of equally spaced angles between  $0^\circ$  and  $180^\circ$  when IANG = 1, or the number of user supplied angles if IANG = 2.

ITOT           works in conjunction with NCRDS and NWAVER to write/punch either individual wavelength values of the phase function, (Legendre coefficients and/or scattering fractions) or averaged wavelength values or both on NUNIT: ITOT = 1 for individual wavelengths; ITOT = 2 for averaged wavelengths, ITOT = 3 for both.

KBAKT          the average (sum/NWAVER) back-scattering coefficient per km, integrated over the size distribution.

KEXTT          the average (sum/NWAVER) extinction coefficient per km, integrated over the size distribution.

KSCAT          the average (sum/NWAVER) scattering coefficient per km, integrated over the size distribution.

LLLL            a switching parameter used to control whether or not particle number density is to be calculated from DRYVOL and mass concentration.

LMAX            = 3\*IFIX (AMAX). Integer estimate of the optimal order for Gauss-Legendre quadrature; used only for diagnostic message print.

MQRTE           = 12345, will cause subroutine AGXPT2 to print efficiency factors QT, QS, and QR, and the normalized distribution function for every value of radius used.

NCRDS           = 1 for write/punch only Legendre coefficients on NUNIT:  
                  = 2 write only phase functions and scattering fractions on NUNIT: = 3 write/punch both on NUNIT.

NINDX           the number of aerosol components which will have different optical constants, mass density or mass concentration.

NRADI           the number of values of particle radius to be used in the calculations. (In effect, points on the radius versus size distribution function plot).

NUNIT           defines the device on which output data may be stored or punched; may be used to place nominal card output into data files, on tape, etc. The default value (NUNIT = 0) is 4.

NWAVE           the number of wavelengths or relative humidity values to be treated in a given run. DWAVE has to be less than  $10^{-4}$  for the latter.

OL(I)           the average Legendre expansion coefficients.  
                  OLT(I)/ENWAVE.

OLT(I)        the total Legendre expansion coefficients (summed over all values of 'WAVE').

OUT( )        an array used for storing some of the numbers to be printed later.

PL(I,J)       the Legendre polynomials of order (I-1) and argument C(J). C(I) are cosines of the scattering angles.

PSUM(I)       the average phase functions integrated over the size distribution.

PSUMT(I)      the total phase functions integrated over size distribution and summed over wavelength.

QATTEN        the attenuation coefficient in square meters per milligram of aerosol material for each wavelength.

R(NRADI)      the radius of the largest particle encountered.

RELHUM        the relative humidity in percent.

SCAT(I)       the scattering fractions as defined in ACT for each wavelength. 'IT' elements in the array.

SCATT(I)      the average (sum/NWAVE) scattering fractions (ACT).

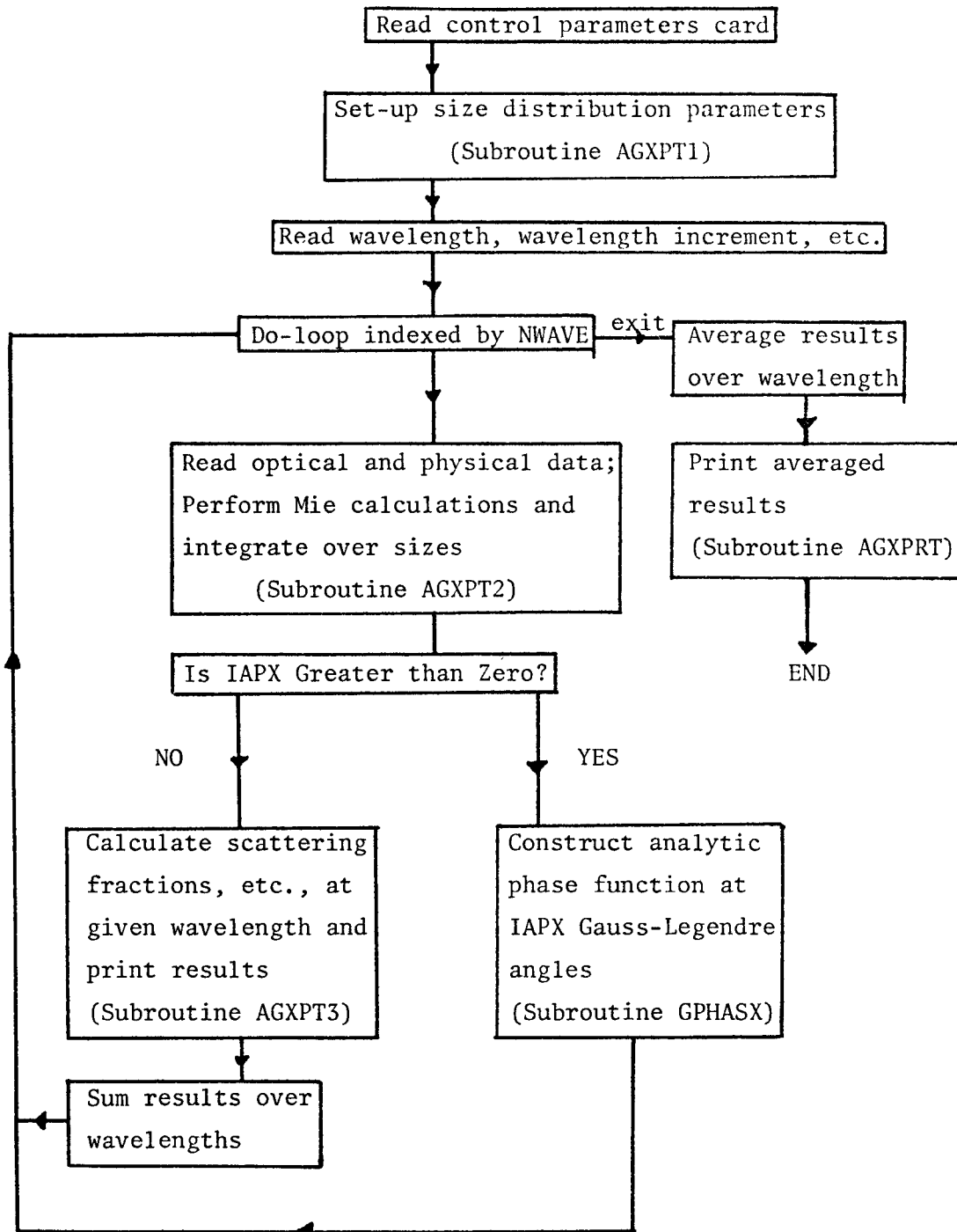
TEMP          the temperature of the atmosphere in degrees C.

TMASS         the total mass of aerosol in  $\text{gm/cm}^3$  in the atmosphere.

VOL           the average volume per particle in cubic micrometers.

WAVE          the first wavelength, in micrometers, at which calculations are to be done.

# AGAUSX (MAIN PROGRAM) - SIMPLIFIED FLOWCHART



## SUBROUTINE AGXPT1

Readers of the following descriptions of the mathematical procedures should bear in mind that the general AGAUS single scattering code computes a number of quantities associated with the Mie theory of the interaction of a single spherical scatter and then averages those quantities using the aerosol size distribution function,  $f(r)$ , as a weighting factor. The following definitions may also be helpful.

The terms "component" or "aerosol component" apply to cases in which the overall aerosol may be a mixture of different materials whose optical properties, mass density, growth factors, or mass concentrations are not identical. The number of "components" to be used in a run is specified by input parameter NINDX. An example of a multi-component aerosol might be one which is a mixture of hygroscopic and nonhygroscopic particles.

The terms "size interval" and/or "original interval" refer to subdivisions of the total range of aerosol radii ( $R_{\text{minimum}} = \text{RLO}$  to  $R_{\text{maximum}} = \text{RHI}$ ) within which the halving and convergence testing procedures are applied independently.

Most averages that must be done are of the form

$$G \equiv \int_{\text{RLO}}^{\text{RHI}} dr f(r)G(r)/\text{FSUM}, \quad (67)$$

where  $G(r)$  is some Mie theory quantity for a particle of radius  $r$ , and a given optical type (refractive index  $m = m - ik$ ), and

$$\text{FSUM} = \int_{\text{RLO}}^{\text{RHI}} dr f(r).$$

The size distributions  $f(r)$ ,  $RLO \leq r \leq RHI$ , may be given in analytic form, or numerically on a set  $\{R(J)\}$  of values of  $r$ . They may or may not be normalized to unity (FSUM may equal 1.0, or not). The relevant Mie theory quantities include  $C_{ext}(r)$ ,  $C_{sca}(r)$ ,  $p(r, \mu)$  for each Gauss-Legendre  $\mu$ , etc. Other averages that must be done have somewhat different forms, e.g.,

$$\tilde{\omega}_n = \frac{1}{C_{ext}} \int dr f(r) \tilde{\omega}_n(r) C_{ext}(r) / \text{FSUM}, \quad (68)$$

for the coefficients  $\tilde{\omega}_n$  of the phase function expression.  $p(\mu) = \sum_{n=0}^{\infty} \tilde{\omega}_n P_n(\mu)$ , in terms of the coefficients  $\tilde{\omega}_n(r)$  of the phase function  $p(r, \mu) = \sum_{n=0}^{\infty} \tilde{\omega}_n(r) P_n(\mu)$ .

The above integrals over  $r$  must be done numerically. In order to minimize computation time, the number of points in the numerical integration should be chosen as small as possible, consistent with adequate accuracy. Each value of  $r$  that is used requires the full Mie calculation for the quantities  $C_{ext}(r)$ ,  $C_{sca}(r)$ ,  $p(r, \mu)$  for each  $\mu$ , etc., these calculations absorb a large part of the total computation time. It has been found in this work that, instead of fixing the number of values of  $r$  to be 500, adequate accuracy results, in many cases, for as few as 50 to 100 values of  $r$ ; this reduction allows a reduction in total computation time by roughly a factor of 4 to 8.

The numerical integration method which was developed makes use of successive halving of intervals until a preset convergence criterion is met. This halving method allows an initial set of unequal intervals to be chosen. For example, suppose that the distribution function  $f(r)$  is sharply peaked around some value of  $r$ , and also has a long tail, as in figure 10. Then it makes

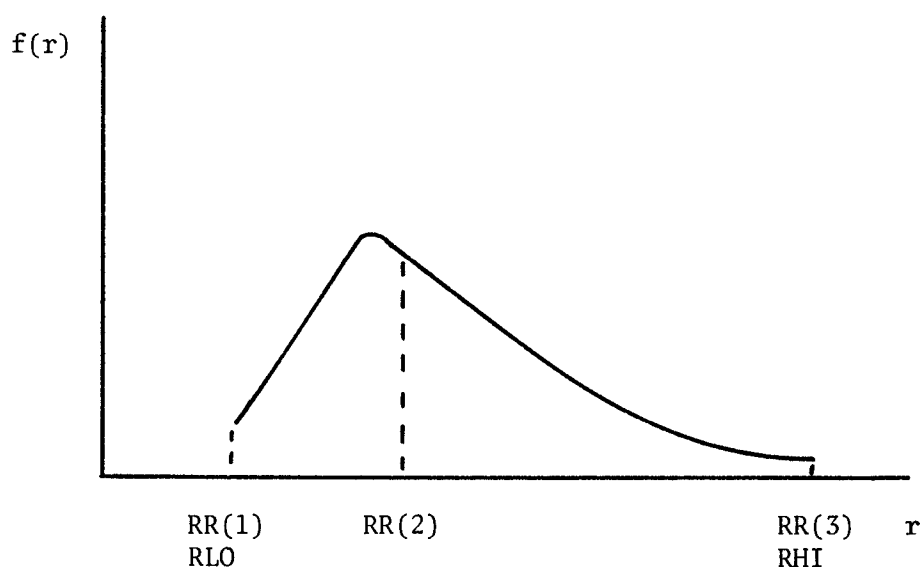


FIGURE 10: Sketch of a hypothetical size-distribution.

The logical flow through the halving integration of AGXPT1 is as follows:

(1) Given RLO, RHI and  $f(r)$ ,  $RLO \leq r \leq RHI$ , in analytic form; or  $f(r)$  numerically on the equally spaced set  $r = R(J)$ ,  $J = 1, NRADI$ .

(2) For the given  $f(r)$ , RLO, RHI, choose the number and size of the original intervals. That is, choose  $RR(I)$ ,  $I = 1, NLAST = 2^{**}MIN + 1$ , with  $RR(1) = RLO$ ,  $RR(NLAST) = RHI$ . Note that  $NI = \text{number of initial intervals} = 2^{**}MIN = 1, 2, 4, 8, 16, \dots$ . Then set  $NHALV = \text{number of halvings in each interval} = MAX - MIN$ , and  $NK = \text{maximum number of points in each interval} = 2^{**}NHALV$ .

(3) The maximum number of points allowed in  $NMAX = 1 + 2^{**}MAX$ . In this work,  $MAX = 9$  was used, so  $NMAX = 513$ . Calculate  $R(KK)$ ,  $F(KK) = f(R(KK))$ ,  $KK = 1, NMAX$ , on all the points  $R(KK)$  which might be used if

the halving goes all the way to NMAX points. For  $f(r)$  given numerically, this is done by linear interpolation.

(4) Calculate  $C_{\text{ext}}(I) = \int_{RR(I)}^{RR(I+1)} dr f(r) C_{\text{ext}}(r)$  in each interval number  $I$ ,  $I = 1, NI$ , by halving of that interval and the trapezoidal rule, until the convergence criterion is met in that interval, or until the halving has progressed all the way to NK points, the maximum number allowed in any interval.

At the same time, calculate  $FSUMG(I) = \int_{RR(I)}^{RR(I+1)} dr f(r)$ , and all other needed

averages  $G(I) = \int_{RR(I)}^{RR(I+1)} dr f(r) G(r)$ , on the same set of points used for  $C_{\text{ext}}(I)$ .

(This means that the convergence criterion is applied only to  $C_{\text{ext}}(I)$ ). Then

$C_{\text{ext}} = \sum_{I=1}^{NI} C_{\text{ext}}(I)$ ,  $FSUM = \sum_{I=1}^{NI} FSUM(I)$ , etc.; then  $C_{\text{ext}} = C_{\text{ext}}/FSUMG$ ,

$G = G/FSUMG$ . The last step is equivalent to making  $\int_{RLO}^{RHI} dr f(r) = 1.0$ .



sense to choose unequal initial intervals as shown. The numerical integration then proceeds by halving each of the original intervals, until the convergence criterion is met. The convergence criterion that was used is the requirement that  $|G^{(n+1)} - G^{(n)}|/|G^{(n)}| < \Delta$ , where  $\Delta$  is some small preset number. Here  $G^{(n)}$  is the value of the integral  $G$  after the  $n$ th halving, separately in each initial interval. The trapezoidal rule was used throughout. The value of the integrand at any given point  $r$  is calculated just once; it does not have to be recalculated on that point after halving.

### Description of Types of Distributions

#### IDSTP

#### DESCRIPTION

- 0 This is an arbitrary user-supplied distribution. 'NRADI' + 1 cards will be read; the first card contains RLO and DELLR ( $\mu$ m). The rest of the cards carry the values of  $F(J)$  and must be in order of increasing radius value.
- 1 This is the zero-order log-normal distribution: the distribution function is given by

$$F(R) = \frac{1}{\sqrt{2\pi} \log_e(\sigma) R} \exp\left\{ -\frac{1}{2} \left[ \frac{\log_e(R/\bar{R})}{\log_e(\sigma)} \right]^2 \right\} .$$

$R \equiv \text{RBAR}$ ;  $\sigma \equiv \text{SIGMA}$ , is the standard deviation. This distribution type requires one input data card to read in the values of  $\bar{R}$ ,  $\sigma$ , RLO and RHI.

2 This is called the double exponential distribution and its distribution function is given by  $F(R) = QA \exp(-AR) + (1-Q)B \exp(-BR)$ .  $Q \equiv \text{CUE}$ . This distribution type requires one input data card to read in the values of RLO, RHI, Q, A, and B. Q is dimensionless while A and B have units of  $\mu\text{m}^{-1}$ .

3 This model (Deirmendjian's "Model C") does not require any input data card. It carries fixed value of DENS, RLO, and DELRD. RHI is determined by the input parameter NRADI.

$$\begin{aligned} F(R) &= 450.2 & R &\leq .08 \\ &= 2.251 * \text{DEL RD} * R^{-4} & R &> .08 \end{aligned}$$

4 The distribution function of this model (Junge distribution) is given by  $F(R) = QR^{-A}$ ,  $Q \equiv \text{CUE}$ . This distribution type requires one input data card to read in RLO, RHI, A, A.

5 The distribution function for the Modified Gamma/Generalized Khirgian-Mazin distribution is

$$F(R) = R^{\alpha} \exp \left[ -\left(\frac{R}{R_c}\right)^{\gamma} \cdot \frac{\alpha}{\gamma} \right], \alpha \equiv \text{ALF}, \gamma \equiv \text{GAM}, \text{ and}$$

$R_c \equiv \text{RC}$ . One input card is needed to read in RLO, RHI, RC, ALF, GAM, and ELWC. ELWC is not needed for type 5 distribution and therefore can be left blank.

6 The size distribution model (NMSU Fog or Cloud Model) is very similar to type 5, except that the user must supply one additional input parameter--namely, the liquid water content (ELWC) in gm/cc. This model can be used for treating situations involving liquid water aerosols like clouds or fogs. For type 6 runs one does not need to read in the values of EMA, CAYA, RHOA, CONC.

- 7 This distribution is essentially same as Junge's distribution (type 4) except that it has fixed parameters. One input card is needed to read in VIS (visibility in km); VIS is used in calculating DENS.
- 8 This is a fixed parameter Continental Bi-modal Model. It does not require an input data card.
- 9 This is a fixed parameter Maritime Bi-modal Model. It does not require an input data card.
- 10 This is a fixed parameter Urban Bi-modal Model. It does not require an input data card.
- 11 This is a user-supplied Bi-modal Model. This requires one input card to read in FOA, FOC, SGA, SGC, RBARA, RBARC. Types 8, 9, 10, and 11 use the sum of two log-normal distributions:

$$F(R) = \sum_{i=1}^2 \frac{N_i}{\sqrt{2\pi} \log_e(\sigma_i) R} \exp - \frac{1}{2} \frac{\log_e(R/\bar{R}_i)^2}{\log_e(\sigma_i)}$$

$N_1 \equiv \text{FOA}$ ,  $R_1 \equiv \text{RBARA}$ ,  $\sigma_1 \equiv \text{SGA}$  with similar meaning for  $N_2$ ,  $R_2$ , and  $\sigma_2$ . Note that in Type 8, 9, 10 the values of SGA and SGC are  $\log_e(\sigma)$ .

- 12 This model (Marshall-Palmer Rain Model) is a simple exponential model which assumes an empirical relationship between rain rate and droplet size distribution parameters:

$$F(D) = N_0 \exp(-\lambda D).$$

$N_0 = 0.08 \text{ cm}^{-4}$ , and  $\Lambda = 41(\text{RN})^{-0.21}$  in which  $\text{RN} = \text{RAIN}$  is the rain rate in mm/hour. Diameter  $D$  is in cm. The corresponding size distribution function of radius  $R$  is given by

$$F(R) = 2N_0 \exp(-2\Lambda R).$$

This distribution requires one input data card to read in RAIN. The values of RLO and RHI are fixed at 0 and 0.5 cm respectively. Due to the limitations on the range of Mie-sizes (subroutine MIEGX) type 12 usage is limited to wavelengths of the order of 1 mm or larger. Since subroutine WATER does not contain optical data for wavelengths longer than 0.2 mm, type 12 runs require the user to supply the values of EMA, CAYA, and RHOA as if rain were a non-aqueous aerosol.

<u>SYMBOL</u>	<u>Explanation or Definition</u>
A	parameter in several distribution types.
ALF	parameter in modified gamma distribution.
AVOL	the average volume per particle in cubic microns obtained via analytical integration over the limits $\text{RLO} = 0$ and $\text{RHI} = \infty$ . That has only been done for $\text{IDSTP} = 5, 6, 8, 9, 10, 11, 12$ .
DENA	temporary storage.
DENC	temporary storage.
DENS	the particle number density in $\text{cm}^{-3}$ .
DELR	increment of radius for arbitrary distribution.
DELRD	$= (\text{RHI} - \text{RLO}) / \text{RADS}$ ; increment between successive values of $R$ .
DELLR	increment in radius for the case $\text{IDSTP} = 0$ .

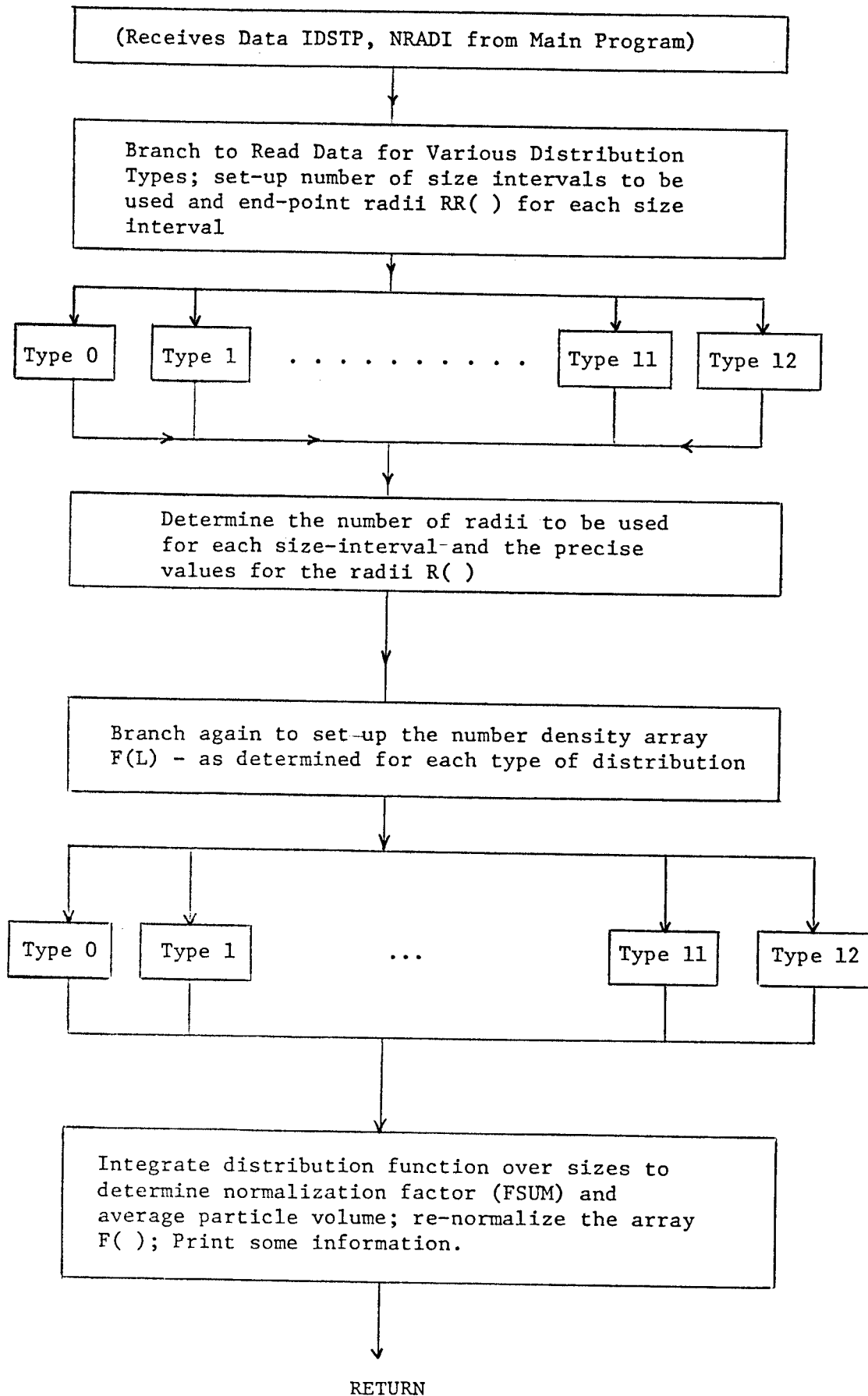
SYMBOL	Explanation or Definition
DR ( )	initial size interval $I = 1, NI$ .
EM	real part of refractive index of actual aerosol particle.
EMM	refractive index of medium in which scattering particles are deployed.
F(J)	the array containing 'NRADI' values of the size distribution function. See the description of AGXPT1 for more details.
FKK	value of distribution function at radius $R(KK)/$
FSUM	the numerical integral over the size distribution function with respect to radius between the limits RHI and RLO; used to normalize the distribution function.
GAM	parameter in modified gamma distribution.
GNUM	temporary storage.
GNUMA	temporary storage.
GNUMC	temporary storage.
IDSTP	identifies the type of aerosol size distribution to be used.
IW	switch for "all water" mode.
NCRDS	not used in this subroutine.
NHALV	maximum number of interval halvings allowed for each initial interval.
NI	number of initial intervals for halving integration.
NKG	maximum number of points which may be used in each initial interval.
NLAST	number of radii, $RR(I)$ , defining the NI basic size intervals.
NMAX	maximum number of points which may be used in halving method.

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\*The pre-coded (IDSTP = 8,9,10) values of SGA and SGC are the natural logarithms of the standard deviations.

<u>SYMBOL</u>	<u>Explanation or Definition</u>
NRADI	the number of radius values to be used in describing the size distribution function for type zero and 3 only.
RAIN	parameter in Marshall-Palmer rain model.
RBAR	mean radius in log-normal distribution.
RBARA	mean radius of "accumulation" mode for bimodal distribution.
RBARC	mean radius of "coarse" mode for bimodal distributions.
RC	mode radius in modified gamma distribution.
RHI	maximum particle radius for any size distribution ( $\mu\text{m}$ ).
R(J)	the array containing 'NRADI' values of radius (particle size) in micrometers.
RLO	minimum particle radius for any size distribution ( $\mu\text{m}$ ).
RR(I)	lower radius of Ith initial interval: $RR(1) = RLO$ , $RR(NLAST) = RHI$ .
SGA	standard deviation* for user supplied bi-modal log normal distribution.
SGC	standard deviation* for user supplied bi-modal log normal distribution.
SIGMA	standard deviation in log-normal distribution: used later as $\ln(\text{SIGMA})$ .
VIS	visibility in km.
VOL	the average 'dry' volume per particle (in $\mu\text{m}^3$ ) calculated numerically.
VOLA	particle volume.
VOLC	particle volume.

# Subroutine AGXPT1 - Simplified Flow Chart



## SUBROUTINE AGXPT2

Subroutine AGXPT2 deals with the most important computational aspects of AGAUSX. If RELHUM and the growth factor (EMUA) are non-zero, AGXPT2 makes adjustments in particle radii, density and refractive index of aerosol material to account for the absorption of water by aerosol particles. These adjustments are made through the following equations:

Radius:  $RT = AC \cdot R(L) - BC/AC,$

Index of Refraction:

i) Real part:  $EM = EMW + (EMA - EMW)/A,$

ii) Imaginary part:  $part\ CAY = CAYW + (CAYA - CAYW)/A$

Density:  $RHO = RHOW + (RHOA - RHOW)/A,$

All the symbols used above are explained in detail below.

Next, subroutine MIEGX is called to compute single particle scattering functions QR, QS, QT, and P(J) for each adjusted radius. These scattering functions are weighted and integrated over the size distribution by the trapezoidal method. The convergence of integration for volume and the extinction cross-section is checked, and warnings are printed if the final one or two contributions exceed 5 percent of the previous total values. If there is more than one component (NINDX>1) in the aerosol with different refractive index and density, the above calculation is carried out NINDX times, and results are summed and divided by the total particle number density. In the end, the attenuation coefficients in square meters per milligram of 'wet' aerosol material are calculated. The same value of extinction coefficient is used for calculating both attenuation coefficients.

If IAPX is greater than zero, only the first three coefficients of the Legendre expansion ( $\tilde{\omega}_0, \tilde{\omega}_1, \tilde{\omega}_2$ ) are calculated and stored in array OL( ). This is for subsequent construction of the GHG analytic phase function.



SYMBOL	Definition
A	= $1 + (\text{RHOA}/\text{RHOW}) * \text{EMUA} * \text{CH}$ ; used in making adjustments due to water absorption by aerosol.
AC	= $A^{1/3}$ .
ALBDO	single scattering albedo.
ALPHA	= $2 * \text{PI} * \text{EMM} * \text{RT} / \text{WAVE}$ . Mie size parameter for adjusted radii.
ALPHAD	temporary storage for ALPHA.
BC	= $\text{BHT} * \text{CH}$ ; used in making adjustments in size growth.
BH	= $1.056 * 10^{-3}$ .
BHT	= $\text{BHI}(298/\text{TEMK})$ .
CATTN	the total attenuation coefficient in square meters per milligram of 'dry' aerosol material for each WAVE. However, CTSUM corresponds to 'wet' aerosol.
CATTNW	the total attenuation coefficient in square meters per milligram of 'wet' aerosol material.
CAY	the imaginary part of refractive index of dry aerosol. (Assumed to be negative; do not enter a value with a negative sign on the data card(s)).
CAYO	temporary storage.
CAYW	the imaginary part of refractive index of pure water at a given TEMP (DEG C) and WAVE.
CH	= $\text{FH}/(1-\text{FH})$ .
CONC	the mass concentration in gm/cc of a component of dry aerosol. It is the number of grams of dry aerosol per cubic centimeter of "cloud" or "fog", etc.
CONCT	the total mass concentration in mg/cc of dry aerosol.
CRGG	partial contributions to average radar cross section, for one

<u>SYMBOL</u>	<u>Definition</u>
CRHH	component of aerosol.
CRSUM	the average (sum/DENST) back-scattering cross-section in square micrometers, integrated over the size distribution, for each WAVE.
CRSUMT	value of radar corss section for total aerosol.
CJGG,	partial contributions to average scattering cross section for
CSSH	one component of aerosol.
CSSUM	the averge (sum/DENST) scattering cross-section in square micrometers, integrated over the size distribution, for each WAVE.
CTSUM	the average (sum/DENST) extinction cross-section in square micrometers, integrated over the size distribution, for each WAVE.
CTSUMT	the total extinction cross-section in square micrometers, integrated over the size distribution, for each WAVE.
DEL	fractional change in contribution to volume from $n^{\text{th}}$ to $n+1^{\text{st}}$ halving, for one initial interval.
DELTA	convergence criterion.
DENS	the particle number density per cubic centimeter. See DENSC also.
DENSC	the particle number density per cc for each component of aerosol. It is calculated from mass density and concentration, and average volume per particle. If LLLL=1, the calculated value of DENSC is replaced by DENS, the value of which has been determined or supplied elsewhere.
DENST	the total particle number density per cc. See also DENSC.
DRYVOL	the average volume per particle in cc.
ELWC	the liquid water content in gm/cc.

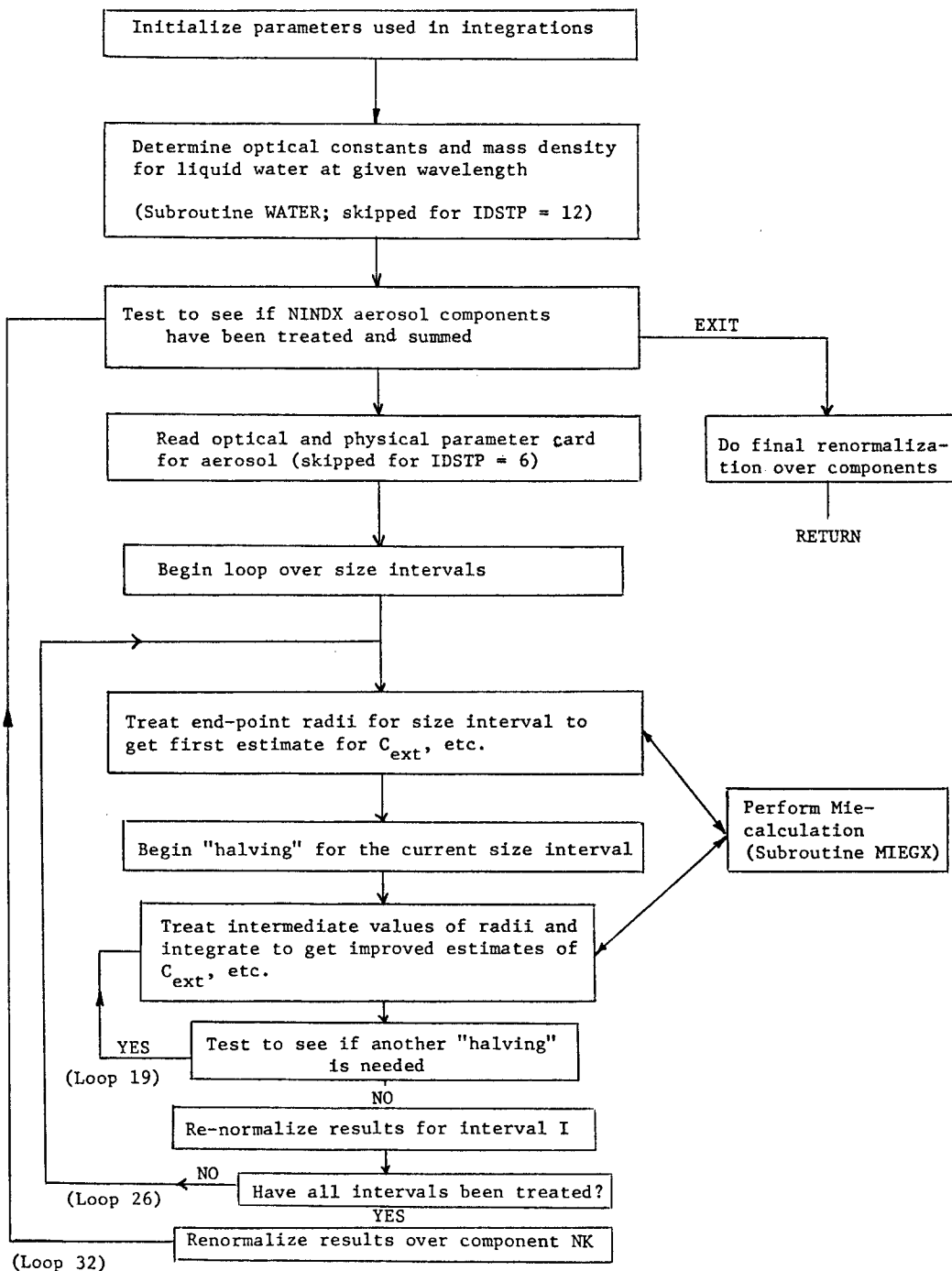
SYMBOL	Definition
EM	the real part of the effective refractive index of 'wet' aerosol. See $CAY\ EM = (EMW + (EMA - EMW)/A)$ .
EMA	the real part of refractive index of the dry aerosol.
EMASS	is 'wet' mass concentration in gm/cc of a component of an aerosol when RELHUM and growth factor are non-zero. EMASS and CONC should have some value if growth factor is zero.
EMM	the refractive index of the surrounding medium, set equal to 1 here implying no surrounding medium.
EMUA	Hanel's mass accretion coefficient $\bar{\mu}$ . Values must be supplied by the user and depend on the type or composition of the aerosol being modeled as well as upon the value of the relative humidity.
EMW	the real part of refractive index of water at a given TEMR (DEG C) and WAVE.
F(I)	the normalized size distribution function (in micrometers <sup>-1</sup> ).
FF(J)	value of arbitrary distribution functions at radius $RP = RLO * (J-1) + DELLR$ , $J = 1, NRADI$ .
FFT	contribution to integral of distribution function from one original interval.
FH	fractional relative humidity (saturation rates).
FKK	value of distribution function at radius $R(KK)$ .
FKKA	geometrical cross section of particle.
FT	partial contribution to integral of distribution function.
H( )	array containing angles.
IAPX	order of expansion for analytic phase function.
IDBLE	precision mode indicator.
IDSTP	identifies the type of aerosol size distribution being used in the run.

SYMBOL	Definition
IERROR	a flag which is set to unity if the number of terms reaches the maximum value allowed in the dimensions of the Mie-coefficients $a_n$ and $b_n$ .
KEXOLD	the extinction coefficient per km summed over the number of components one less than the current value of the running loop index NK.
KEXT	the extinction coefficient per km for each component of the aerosol.
KEXTT	the total extinction coefficient per km for each WAVE.
LLLL	a switch parameter. If LLLL=0, the particle number density (DENSE) is calculated using mass density and concentration, and the average volume per particle (DRYVOL). If LLLL=1, a pre-calculated or pre-supplied value of DENS is used.
MERROR	an error counter: If MERROR exceeds 10, execution is terminated.
MQRTE	= 12345, QT, QS, QR and Fr are printed for each radius.
NCRDS	not used in this subroutine, but appears in a common block.
NHALV	maximum number of interval halvings allowed for each initial interval.
NINDX	the number of aerosol components which will have different optical constants, mass density or mass concentration.
NRADI	the number of points on the radius vs. size distribution function plot.
01STAR	value of $\tilde{\omega}_1$ for a given size parameter.
01STRD	temporary storage for 01STAR.
02STAR	value of $\tilde{\omega}_2$ for a given size parameter.
02STRD	temporary storage for 02STAR.

SYMBOL	Definition
OL( )	Legendre coefficients.
OL1GG,	partial contributions to average $\tilde{\omega}_1$ , for one component of
OL1HH	aerosol.
OL1HHT	contributes to $\tilde{\omega}_1$ of average particle from one original interval.
OL1SUM	value of $\tilde{\omega}_1$ for one component of an aerosol.
OL2GG,	partial contributions to average $\tilde{\omega}_2$ , for one component of aerosol
OL2HH	
OL2HHT	contributions to $\tilde{\omega}_2$ of average particle from one original interval.
OL2SUM	value of $\tilde{\omega}_2$ for one component of aerosol.
OLSTAR	second Legendre coefficient ( $\tilde{\omega}_1$ ).
OM2	third Legendre coefficient ( $\tilde{\omega}_2$ ).
P(J)	an array containing 'IT' average intensity factors $(i_1 + i_2)/2$ for each radius.
PGG(I),	partial contributions to average intensity $(i_1 + i_2)/2$ for one
PHH(I)	aerosol component at abscissa value $\mu_I$ .
PHHT(I)	average intensity at $\mu_I$ for one original interval.
PL( , )	Legendre polynomials.
PSNEW(J)	= P(J)*F(L), where p(J) corresponds to $L^{\text{th}}$ radius, $L \geq 2$ .
PSOLD(J)	= P(J)*F(L), where P(J) corresponds to $(L-1)^{\text{th}}$ radius except when $L=1$ ; in that case PSOLD(J) = P(J)*FF(1), and P(J) corresponds to 1st radius.
PSUM(J)	average intensity factors integrated over the size distribution. They are then summed over NINDEX components and divided by DENST.
PSUMT(J)	final average phase function.
QR	the back-scattering efficiency factor for each radius.
QRD	temporary storage for QR.

SYMBOL	Definition
QS	the scattering efficiency factor for each radius.
QSD	temporary storage for QS.
QT	extinction efficiency factor for a given size parameter.
QTD	temporary storage for QT.
R(L)	the array containing 'NRADI' values of radius in micrometers.
RELHUM	the relative humidity in percent.
RHO	the specific density (in gm/cc) of 'wet' aerosol.
RHOA	the specific density (in gm/cc) of 'wet' aerosol.
RHOW	the specific density (in gm/cc) of water at the temperature TEMP (in DEG C).
RIT	the radius of a particle after taking into account its growth due to absorption of water.
RR(I)	lower radius of I <sup>th</sup> initial interval.
TEMK	the temperature of surrounding medium in degrees Kelvin.
TEMP	the temperature of the surrounding medium in degrees Centigrade.
TMASS	the total mass concentration in gm/cc of 'wet' aerosol.
TVOL	is used to pass the value of DRYVOL from MAIN to subroutine.
VOL	total volume occupied by aerosol material distributed in 1 cm <sup>3</sup> of space.
VOLGG	partial contributions to volume of average particle, for one
VOLHH	component of aerosol.
VOLHHT	contribution to volume of average particle from one original interval.
WAVE	the wavelength in micrometers at which all the scattering functions are computed.

Subroutine AGXPT2 - Simplified Flowchart  
(Receives control data and size distribution data from main program)



### SUBROUTINE AGXPT3

Subroutine AGXPT3 receives the values of various cross-sections and the integrated average intensity factors from AGXPT2 and converts them into directly useful quantities:

Coefficient (per km) =  $10^{-3} \cdot \text{DENS} \cdot \text{cross-section}$ ,

Scattering fractions =  $\frac{\lambda^2}{4\pi^2} \cdot \text{DENS} \cdot \text{intensity factors}$ ,

and Phase function =  $\frac{\lambda^2}{\pi C_{\text{ext}}} \cdot \text{intensity factors}$ .

$\lambda$  is in  $\mu\text{m}$ . It then prints out all single wavelength results.

It also computes albedo for single scattering using equation (4). It then calls on subroutine GAUS which, among other things (see GAUS for details), also returns a value for albedo calculated differently. The two values are compared, and if they differ by more than 0.01 percent the user is advised to rerun the program using a larger value of IT.

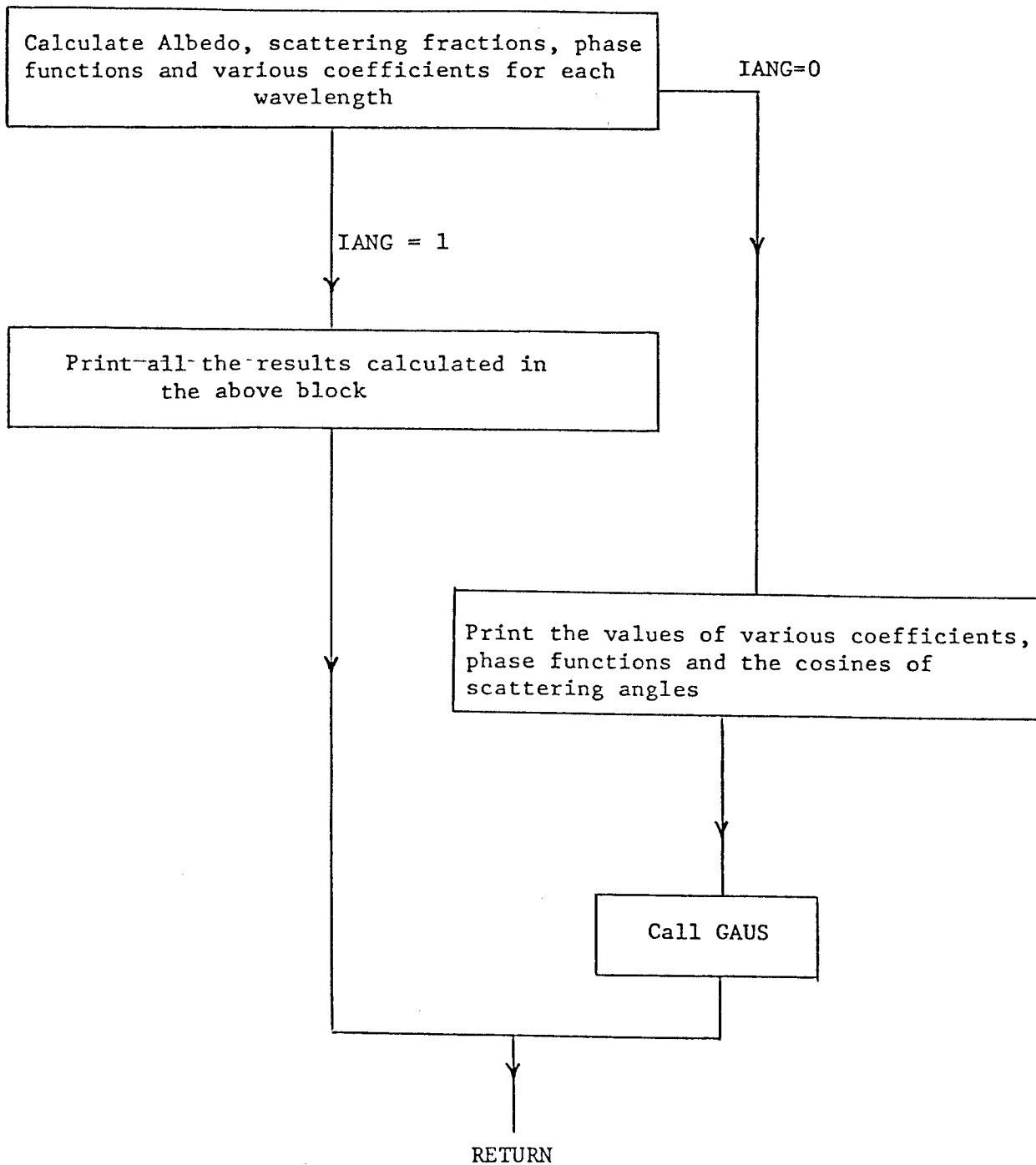
<u>SYMBOL</u>	<u>Explanation or Definition</u>
ALBEDO	= CSSUM/CTSUM; albedo for single scattering.
C(I)	the cosines of scattering angles. 'IT' elements in the array.
CAY	the ratio of the imaginary part to the real part of adjusted refractive index of the last component.
CAYNG	= -CAY.
CRSUM	the average back-scattering cross-section when it is received by AGXPT3 but it returns to MAIN the value of the average scattering coefficient per km.
CSSUM	the average scattering cross-section when it is received by AGXPT3 but it returns to MAIN the value of the average scattering coefficient per km.



<u>SYMBOL</u>	<u>Explanation or Definition</u>
CTSUM	the average extinction cross-section when it is received by AGXPT3 but it returns to MAIN the value of the average extinction coefficient per km.
DENS	the total particle number density in $\text{cm}^{-3}$ .
EM	the real part of the adjusted refractive index of the last aerosol component.
EMM	the refractive index of the surrounding medium. It is set equal to 1 in AGAUSX.
GNU	the wave number in $\text{cm}^{-1}$ .
H(I)	the array containing 'IT' scattering angles (in degrees).
IANG	= 0, for computation of phase functions at 'IT' Gauss-Legendre quadrature angles. = 1, for computation of phase functions and scattering functions at 'IT' equally spaced angles between $0^\circ$ and $180^\circ$ . = 2, for computation of phase functions and scattering fractions at 'IT' user supplied angles.
IDSTP	identities the type of aerosol size distribution to be used.
IT	the order of expansion for phase functions when IANG = 0, the number of equally spaced angles between $0^\circ$ and $180^\circ$ when IANG = 1, or the number of user supplied angles when IANG = 2.
ITOT	used for optional write/punch on NUNIT.
KRSUM	the back-scattering coefficient per km integrated over the size distribution for each WAVE.
KSSUM	the scattering coefficient per km integrated over the size distribution, for each WAVE.

<u>SYMBOL</u>	<u>Definition</u>
KTSUM	the extinction coefficient per km integrated over the size distribution, for each WAVE.
NCRDS	= 1 for write/punch only Legendre coefficients on NUNIT: = 2 write only phase functions and scattering fractions on NUNIT: = 3 write/punch both on NUNIT.
NINDX	the number of aerosol components which will have different optical constants, mass density or mass concentration.
NUNIT	defines the device on which the input and/or output data may be stored in lieu of actual card punching; may be used to place nominal card output into data files on tape, etc. The default value (NUNIT = 0) is 4.
OL(1)	the first coefficient in the Legendre expansion of phase functions. When OL(1) disagrees with ALBEDO by more than 0.01 percent program AGAUSX should be rerun using a larger value of IT.
PFACT	= $WAVE * WAVE / (PI * CTSUM * EMM * EMM)$ . When PSUM(J) is multiplied by PFACT we get the original phase functions.
PSUM(J)	the average intensity factors integrated over the size distribution when received by AGXPT3, but they are the original phase functions for each WAVE when returned to MAIN.
SCAT(J)	contains 'IT' values of scattering fractions for each WAVE.
SFACT	= $WAVE * WAVE * DENS * 10^{-6} / 4 * PI * PI$ . When PSUM(J) is multiplied by SFACT, one gets the scattering fractions of ACT code.
WAVE	the wavelength in microns.

Subroutine AGXPT3 - Simplified Flowchart



# SUBROUTINE MIEGX\*

Subroutine MIEGX computes various efficiency factors, and intensity factors  $i_1$  and  $i_2$  for each complex refractive index  $m$ , size parameters  $\alpha$  and also the first three Legendre coefficients ( $\tilde{\omega}_0$ ,  $\tilde{\omega}_1$ ,  $\tilde{\omega}_2$ ) when IAPX is greater than zero. The Ricatti-Bessel functions and their derivatives in equations (5) and (6) are computed by the forward recursion method. The initial values used in forward recursion are:

$$\psi_0(z) = \sin z,$$

$$\psi_1(z) = \frac{\sin z}{z} - \cos z,$$

$$X_0(z) = \cos z, \text{ and}$$

$$X_1 = \frac{\cos z}{z} + \sin z.$$

[Note:  $\xi_n(z) = \psi_n(z) + i\chi_n(z)$ ]

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\*A Mie-type routine utilizing a continued fractions method of calculation was obtained from W. J. Lentz of the Atmospheric Sciences Laboratory and modified slightly to substitute directly for MIEGX in AGAUSX, thereby eliminating the need for the forward recursion of the Ricatti-Bessel functions. The new routine is more accurate for larger Mie sizes and larger imaginary parts of the index of refraction. This new routine has been validated by New Mexico State University under contract DAAD07-79-M-6275. The rotation has been kept the same between the two routines as much as possible.

The angular functions  $\pi_n$  and  $\tau_n$  are also computed by forward recursions from Equations (24) and (25). The initial values used are  $\pi_0(\theta) = 0$ ,  $\pi_1(\theta) = 1$ ,  $\tau_0(\theta) = 0$ , and  $\tau_1(\theta) = \cos\theta$ .

The Mie series is terminated either when two successive terms have  $(|\operatorname{Re}(a_n)| + |\operatorname{Im}(a_n)| + |\operatorname{Re}(b_n)| + |\operatorname{Im}(b_n)|) < 10^{-5}$ , or when the number of terms exceeds  $(8 + F\alpha)$ .  $F$  is 1.2 for  $\alpha \leq 51$  and is  $1 + 2.26\alpha^{-0.613}$  for  $\alpha > 51$ . The tolerance value of  $10^{-5}$  could be decreased for higher precision, if the user so desires.

The subroutine computes and stores arrays of  $a_n$  and  $b_n$  until convergence is reached and then generates necessary  $\pi_n$  and  $\tau_n$  functions. Finally it computes values of  $Q_{\text{ext}}$ ,  $Q_{\text{sca}}$ ,  $Q_{\text{abs}}$  (absorption)  $i_1$ ,  $i_2$ ,  $Q_{\text{rad}}$  (backscatter),  $p(\theta)$ , and radiation pressure  $Q_{\text{pr}}$ .

<u>SYMBOL</u>	<u>Explanation or Definition</u>
ALPHA	Mie size parameter, $\alpha = 2\pi r/\lambda$ .
C(K)	the array of cosine of the scattering angles. There are 'IT' elements in the array.
CAY	the ratio of the imaginary part to the real part of adjusted refractive index. See AG9PT2.
EM	the real part of adjusted refractive index.
EN	floating point representation of N.
EYE1(K)	$i_1$ (Eq. 15) at angles = Arc cos [C(K)]. 'IT' elements in the array.
EYE2(K)	$i_2$ (Eq. 16) at angles = arc cos [C(K)]. 'IT' elements in the array.
FACT	determines the cutoff criterion to terminate the Mie series. It is equal to 1.2 if $\alpha \leq 51$ and is $1 + 2.26\alpha^{-0.613}$ for $\alpha > 51$ . See Mie theory text.

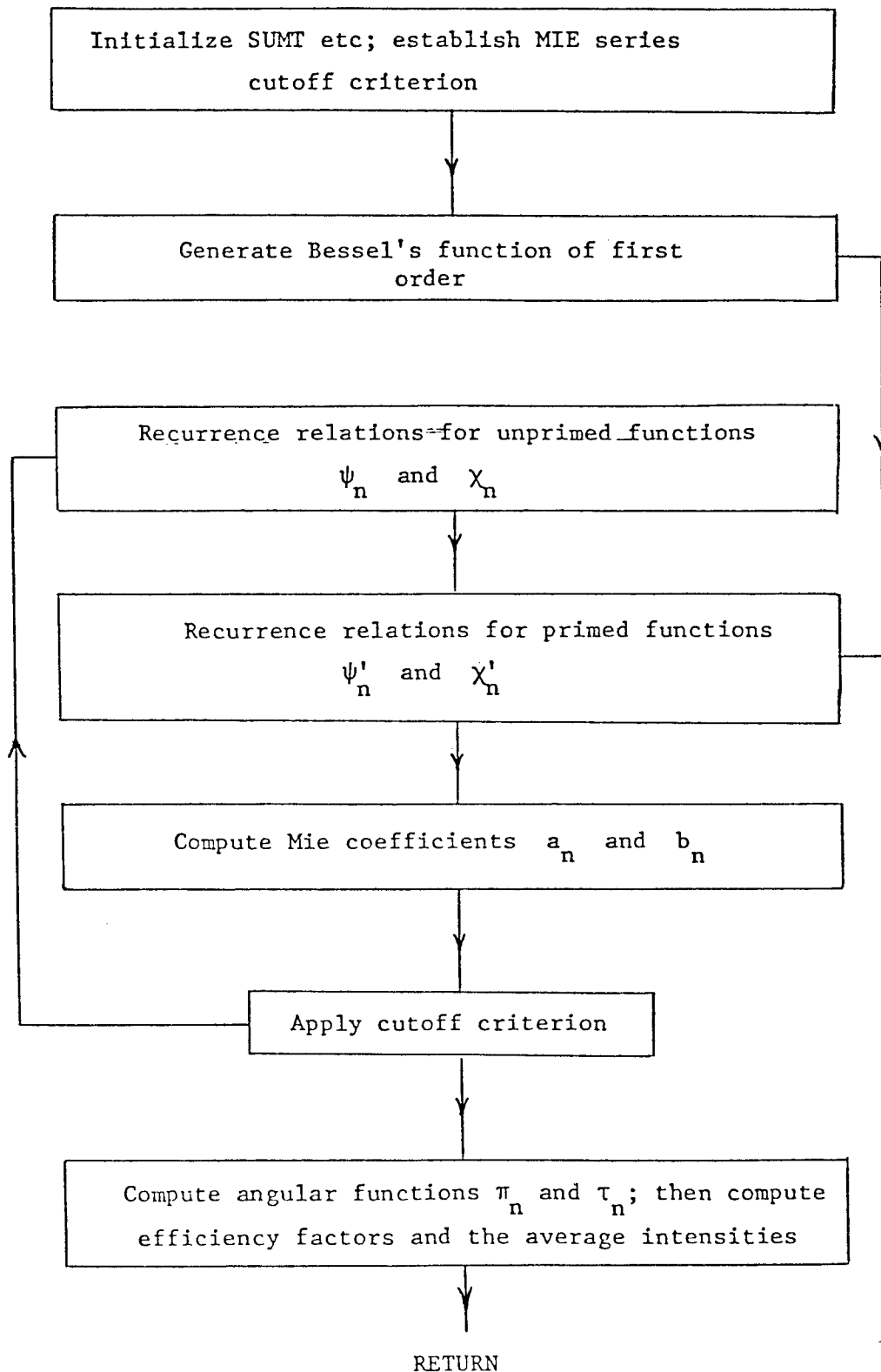
<u>SYMBOL</u>	<u>Definition</u>
FAN(N)	= $\text{Im}(a_n)$ ; Equation (5).
FBN(N)	= $\text{Im}(b_n)$ ; Equation (6).
GAMMA	the true imaginary part of adjusted refractive index.
IERROR	a flag which is set to unity if the number of terms (N) reaches the maximum value allowed in the dimensions of $a_n$ and $b_n$ .
ISW1	a switch parameter used in applying cutoff criterion.
O1STAR	= $\tilde{\omega}_1$ ; first order coefficient for Legendre expansion of the average intensity $P(K)$ .
O2STAR	= $\tilde{\omega}_2$ ; second order coefficient for Legendre expansion of the average intensity $p(K)$ .
P(K)	= $(i_1 + i_2)/2$ , the average intensity at angles, $\text{Arc cos } (C(K))$ . There are 'IT' elements in the array.
PIN	= $\pi_n(\theta)$ ; Equation (17).
REAN	= $\text{Re}(a_n)$ ; Equation (5).
REBN	= $\text{Re}(b_n)$ ; Equation (6).
RN	= $\text{Re}(\psi_n(n\alpha))$ ; Equation (7).
RNL1	= $\text{Re}(\psi_o(n\alpha))$ ; Equation (7).
RPN	= $\text{Re}(\psi'(n\alpha))$ . Prime indicates differentiation with respect to the argument.
SGA	the absorption efficiency factor.
SGMAS	the average value of $\text{Cos}(\theta)$ , where $\theta$ is the scattering angle.
SGMP	the radiation pressure factor $Q_{\text{pr}}$ .
SGR	the back-scattering efficiency factor.
SGS	the scattering efficiency factor.
SGT	the extinction efficiency factor.
SN	= $\text{Im}(\psi_n(n\alpha))$ ; Equation (7).

SYMBOL	Explanation or Definition
SNL1	$= \text{Im}(\psi_o(n\alpha));$ Equation (7).
SPN	$= \text{Im}(\psi'(n\alpha)).$ Prine indicates differentiation with respect to the argument.
SUM11I	the imaginary part of the scattering amplitude $S_1(\theta);$ $\text{Im}S_1(\theta) = \sum \frac{(2n+1)}{n(n+1)} [\text{Im}(a_n)\pi_n(\theta) + \text{Im}(b_n)\tau_n(\theta)].$
SUM12I	the imaginary part of the scattering amplitude $S_2(\theta);$ $\text{Im}S_1(\theta) = \sum \frac{(2n+1)}{n(n+1)} [\text{Im}(b_n)\pi_n(\theta) + \text{Im}(a_n)\tau_n(\theta)].$
SUM11R	the real part of the scattering amplitude $S_1(\theta);$ $\text{Re } S_1(\theta) = \sum \frac{(2n+1)}{n(n+1)} [\text{Re}(a_n)\pi_n(\theta) + \text{Re}(b_n)\tau_n(\theta)].$
SUM12R	the real part of the scattering amplitude $S_2(\theta);$ $\text{Re}S_2(\theta) = \sum \frac{(2n+1)}{n(n+1)} [\text{Re}(b_n)\pi_n(\theta) + \text{Re}(a_n)\tau_n(\theta)].$
SUMRI	$= \sum_{n=1}^N (-1)^n (2n+1) \text{Im}(a_n - b_n).$
SUMRR	$= \sum_{n=1}^N (-1)^n (2n+1) \text{Re}(a_n - b_n).$
SUMS	$= \sum (2n+1) ( a_n ^2 +  b_n ^2).$
SUMS1	$= \sum_{n=2}^N \frac{(n-1)(n+1)}{n} [\text{Re}(a_n)\text{Re}(a_{n+1}) + \text{Re}(b_n)\text{Re}(b_{n+1}) + \text{Im}(a_n)\text{Im}(a_{n+1}) + \text{Im}(b_n)\text{Im}(b_{n+1})].$
SUMS2	$= \sum_{n=1}^N \frac{(2n-1)}{n(n-1)} [\text{Re}(a_n)\text{Re}(b_n) + \text{Im}(a_n)\text{Im}(b_n)].$
SUMT	$= \sum (2n+1) \text{Re}(a_n + b_n).$

<u>SYMBOL</u>	<u>Explanation or Definition</u>
TAUN	$= \tau_n(\theta)$ ; Equation (17).
TERMN	$=  \operatorname{Re}(a_n)  +  \operatorname{Im}(a_n)  +  \operatorname{Re}(b_n)  +  \operatorname{Im}(b_n) $ . TERMN determines the cutoff criterion for terminating Mie series.
TN	$= \psi_n(\alpha)$ ; Equation (7).
TNL1	$= \psi_o(\alpha)$ ; Equation (7).
TPN	$= \psi'(\alpha)$ ; prime indicates differentiation with respect to the argument.
UN	$= \chi_n(\alpha)$ ; Equation (8).
UNL1	$= \chi_o(\alpha)$ ; Equation (8).
UPN	$= \chi'_n(\alpha)$ ; prime indicates differentiation with respect to the argument.



Subroutine MIEGX - Simplified Flowchart



### SUBROUTINE ANGLE

Subroutine ANGLE is called when IANG = 1 or 2. It is used to compute the values of 'IT' equally spaced scattering angles between 0° and 180° or a read in set of user-supplied angles. It places these angle values in the array, H(I). It also computes the cosines of those angles and places them in the array C(I).

<u>SYMBOLS</u>	<u>Explanation</u>
C(I)	the array containing the cosines of scattering angles in the array H(I).
H(I)	the array containing !IT! scattering angles (in degrees).
IT	is the number of scattering angles chosen between 0° and 180°.
RADS	=PI/180.

### SUBROUTINE GUSET

Subroutine GUSET uses the Davis and Rabinowitz algorithm<sup>11</sup> to choose n values of  $\cos\theta_{kn}$  ( $k = 1, 2, \dots, n$ ) between the interval  $-1 \leq \cos\theta \leq 1$  and the corresponding values of quadrature weights  $a_{kn}$ . The abscissas,  $\cos\theta_{kn}$  are the n zeros of the Legendre polynomials  $P_n(\cos\theta_{kn})$ , while the weights are given by

$$a_{kn} = 2(1 - x_{kn}^2) / [nP_{n-1}(x_{kn})]^2 \quad (65)$$

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<sup>11</sup>P. Davis and P. Rabinowitz, 1956, J Res NBS, 56:35

Initial estimates of the zeros are obtained from the  $n$  successive zeros of the Bessel function ( $j_0(j_k) = 0$ ) via

$$x_{kn} = \cos [j_k / ((n + \frac{1}{2})^2 + (1 - (\frac{2}{\pi})^2)/4)^{1/2}]. \quad (66)$$

final values of the  $x_{kn}$  are found by Newton-Raphson iteration. The tolerance of Legendre polynomial zeros is set at  $10^{-14}$ .

<u>SYMBOL</u>	<u>Explanation</u>
AKN(k)	$a_{kn}$ (Eq. 32). 'IT' elements in the array.
IT	$n$ ; it is the order of Legendre expansion for phase functions.
P(N)	Legendre polynomials, $p_n(x)$ .
X	$x_{kn}$ (Eq. 33).
XKN(K)	$\cos \theta_{kn}$ ; $p_n(\cos \theta_{kn}) = 0$ within $10^{-14}$ .
TOL	the tolerance of zeros of Legendre polynomials = $10^{-14}$ .
Z(I)	$j_k$ (Eq. 33). $I, k = 1, 2, \dots, IT$ .

#### SUBROUTINE GAUS

Subroutine GAUS computes the Legendre polynomials as PL(,) and computes Legendre expansion coefficients given by equation (31) numerically. To do that the integral in equation (31) is replaced by summation as follows:

$$\tilde{\omega}_\ell = \frac{(2\ell+1)}{2} \sum_{k=1}^n p(\theta_{kn}) p_\ell(\cos \theta_{kn}) a_{kn},$$

where  $\theta_{kn}$  and  $a_{kn}$  have the meaning as given in subroutine GUSSET.

Using the values of coefficients  $\tilde{\omega}$  and equation (30), the phase functions are reconstructed and called  $p_c(\theta_{kn})$ . GAUS then computes the root mean square deviation between the original phase functions  $p(\theta_{kn})$  and the reconstructed phase functions  $p_c(\theta_{kn})$  as each successive term is added to the series in equation (30). Finally it prints out the values of coefficients and rms deviations.

<u>SYMBOL</u>	<u>Explanation or Definition</u>
F	is the array containing the original phase function $p(\theta_{kn})$ .
IT	is the order of Legendre expansion for phase functions.
NCRDS	= 1 for write/punch only Legendre coefficients on NUNIT: = 2 write only phase functions and scattering fractions on NUNIT: = 3 write/punch both on NUNIT.
NUNIT	defines the device on which the input and/or output data may be stored in lieu of actual card punching; may be used to place nominal card output into data files or tape, etc. The default value (NUNIT=0) is 4.
OL(LL)	the array containing coefficients $\tilde{\omega}_l$ .
PL(,)	Legendre polynomials (equivalenced in MIEGX).
PC(I)	the array containing the reconstructed phase functions $p_c(\theta_{kn})$ .
RMS(J)	the rms deviation between the original phase functions and the reconstructed phase functions.

## SUBROUTINE WATER

The purpose of subroutine WATER is to relieve the user of program AGAUS of the task of looking up and keypunching data on the index of refraction and mass density of liquid water. This routine receives the wavelength ( $\mu\text{m}$ ) and temperature ( $^{\circ}\text{K}$ ) from the calling program as variables WVD and TEMPD. It returns the mass density through variable DENSD, and the real and imaginary parts of the refractive index of liquid water through the variables EMD and CAYD, respectively.

The data on optical constants coded into routine WATER were taken from the tabulation by Irvine and Pollack<sup>9</sup> and the water densities were taken from a copy of the CRC Handbook of Chemistry and Physics. Tabulated values of the real (m) and imaginary (k) parts of the refractive index are available for the wavelength range 0.20 $\mu\text{m}$  to 200 $\mu\text{m}$ , and are entered at uniform wavelength increments. Values of the real (m) and imaginary (k) parts of the refractive index at wavelengths other than found in the table are estimated through straight-line interpolation. Linear interpolation is also used between tabulated temperatures in calculating the mass density  $\rho_w$  (= DENSD).

### Methods Used

Subroutine WATER conducts separate binary searches of the wavelength table LAMBDA() and temperature table TEMP() to find the indices L and L+1 which bracket the received wavelength (WVD) and temperature (TEMPD). It then uses linear interpolation to get estimated values of EMT, (M), CAYT, (k), and RHODEN ( $\rho_w$ ).

The interpolation formula can be written as

$$y(x) = y(x_{\ell}) + \left[ \frac{y_{\ell+1} - y_{\ell}}{x_{\ell+1} - x_{\ell}} \right] (x - x_{\ell}),$$

with  $y = m, k$  or  $\rho_w$  and  $x = \text{wavelength or temperature}$ .

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<sup>9</sup>W. M. Irvine and J. B. Pollack, 1968, "Infrared Optical Properties of Water and Ice Spheres," Icarus, 8:324

<u>SYMBOL</u>	<u>Explanation or Definition</u>
CAYD	imaginary part of refractive index k.
CAYT	the interpolated value of k in single precision form; used intermediately to hold summed quantities.
DENS	interpolated result for the mass density of liquid water - $\rho_w$ .
EMD	real part of index of refraction - m.
EMT	the interpolated result for the real part of the refractive index.
H	an indexing (integer) parameter.
L	an integer indexing parameter.
LAMBDA ( )	array of wavelengths at which data are entered for m and k; [typed as "real"].
NSUBI( )	array of values for k (or, $n_{\text{imaginary}}$ ); [typed as "real"].
NSUBR	array of data entries for m (or, $n_{\text{real}}$ ) [typed as "real"].
P	an (integer) indexing parameter.
POINT	an (integer) indexing parameter.
TEMP( )	array of temperature values ( $^{\circ}\text{K}$ ) at which entries for $\rho_w$ exist.
TEMPD	temperature at which $\rho_w$ is to be found.
TMCHUR	temperature at which value of $\rho_w$ is desired.
RHODEN	interpolated result for $\rho_w$ .
WAVE	single precision version of wavelength at which values of n and k are desired.

## SUBROUTINE AGXPRT

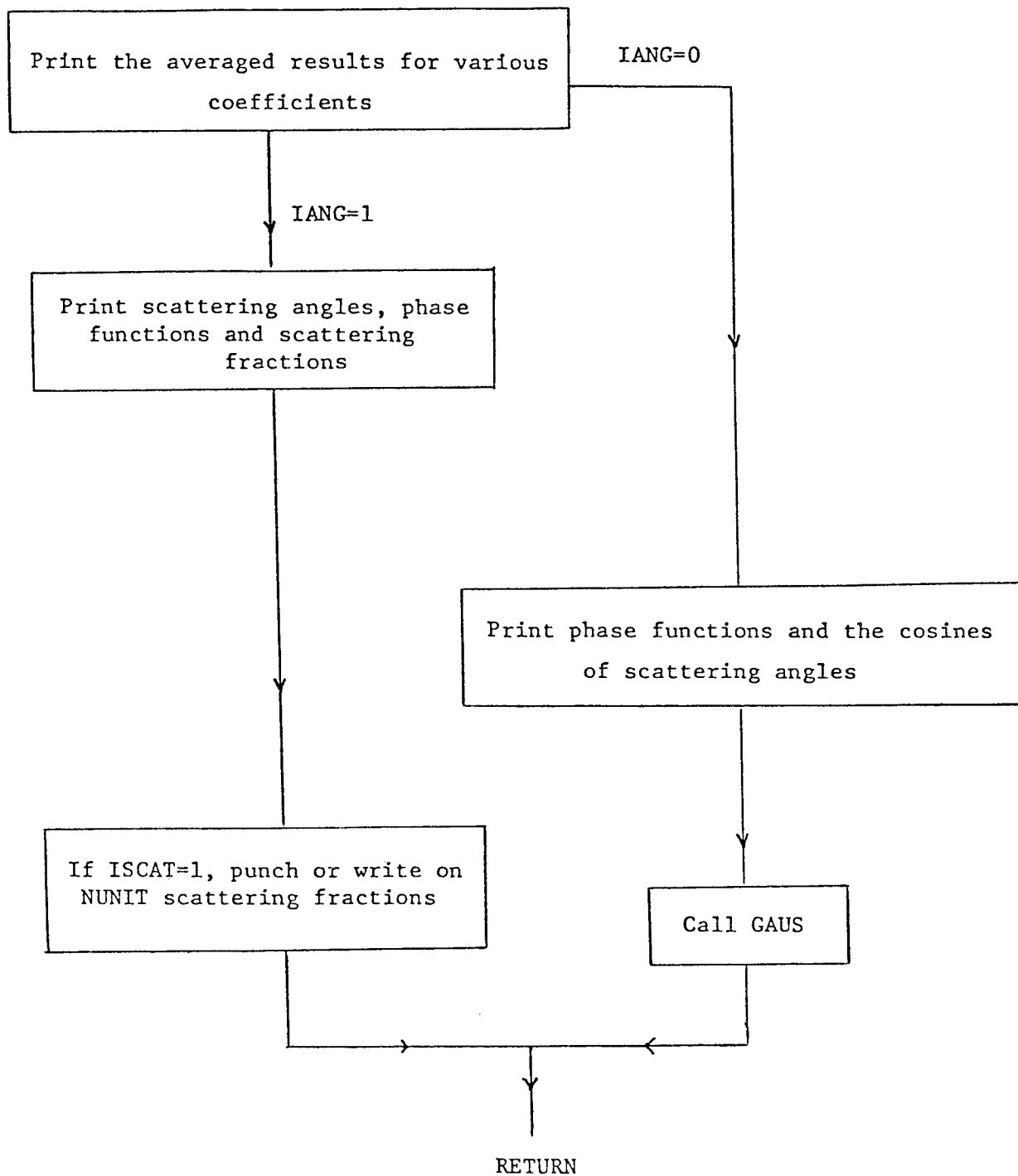
Subroutine AGXPRT prints out all the averaged (sum/NWAVE) results essentially in the same way as AGXPT3 does for each wavelength if IAPX = 0. If IANG = 0, subroutine GAUS is called to generate Legendre expansion coefficients which are used to reconstruct the averaged phase functions. GAUS also computes the root mean square deviation between the original phase function and the reconstructed phase functions. See the section on subroutine GAUS for more details. If IANG = 1 or 2, the above calculation is skipped.

<u>SYMBOL</u>	<u>Explanation or Definition</u>
C(I)	the cosines of scattering angles. 'IT' elements in the array.
CATTN	the average (sum/NWAVE) attenuation coefficient in square meters per milligram of aerosol material.
H(I)	the array containing 'IT' scattering angles (in degrees).
IANG	= 0, for the computation of phase functions at 'IT' Gauss-Legendre quadrature angles. = 1, for the computation of phase functions and scattering fractions at 'IT' equally spaced angles between 0° and 180°.
IT	the order of Legendre expansion for phase functions when IANG = 0, or the number of equally spaced angles between 0° and 180° when IANG = 1, or the number of user-supplied angles when IANG = 2.
KBAKT	the average (sum/NWAVE) back-scattering coefficient per km, integrated over the size distribution.
KEXTT	the average (sum/NWAVE) extinction coefficient per km, integrated over the size distribution.
KSCAT	the average (sum/NWAVE) scattering coefficient per km, integrated over the size distribution.

<u>SYMBOL</u>	<u>Explanation or Definition</u>
NUNIT	defines the device on which the input and/or output data may be stored in lieu of actual card punching; may be used to place nominal card output into data files on tape, etc. The default value (NUNIT=0) is 4.
NWAVE	the number of wavelengths or relative humidity values to be treated in a given run.
PSUM(J)	the array containing the values of average (sum/NWAVE) phase function integrated over the size distribution.
SCATT(J)	the array containing the values of average (sum/NWAVE) scattering fractions.



Subroutine AGXPRT - Simplified Flowchart



## SUBROUTINE GPHASX

Subroutine GPHASX constructs the GHG analytic phase function. The required input consists of the phase function at zero degrees,  $\tilde{\omega}_0$ ,  $\tilde{\omega}_2$ , and the order of Legendre expansion, L. The parameter g, denoted by G1 in the subroutine, is then determined by an iterative process: note  $0 \leq g \leq 1$ . We then determine  $\alpha$  and subsequently proceed to construct the GHG phase function, checking to insure that the phase function does not go negative; if it does, we leave the current loop and starting from the previous value of  $\mu$  (for which the phase function was positive), continue to construct the GHG phase function from the modified HG phase function. The GHG phase function is then renormalized and the appropriate Legendre coefficients are constructed.

<u>SYMBOL</u>	<u>Explanation or Definition</u>
ALPHA	$.5[\tilde{\omega}_2/(\tilde{\omega}_0 G^2)-1]$ .
C	$P(1)/\tilde{\omega}_0$ .
COEF	Array containing first three Legendre coefficients $(\tilde{\omega}_0, \tilde{\omega}_1, \tilde{\omega}_2)$ .
DELL	Iterative increment in determination of G
DEN	$1 + G^2 - 2\mu G$ ; $\mu = \cos\theta$ .
DENOM	$(1 + G^2 - 2\mu G)^{1/2}$ .
ELHS	$G[(1 - G^2)P(1)/\tilde{\omega}_0 - 1 + 3G/2]$ .
EMO	Array containing Gauss-Legendre angles.
EMU	Array containing cosines of Gauss-Legendre angles.
ERR	Error in integrated GHG phase function.
G	Parameter in GHG phase function.
GPFN	Array containing GHG phase function.

<u>SYMBOL</u>	<u>Explanation or Definition</u>
GSQ	$G * G.$
ITR	number of iterations in the determination of G; 100 iterations maximum.
NUNIT	Auxiliary unit for writing/punching Legendre coefficients for GHG phase function.
OM	Array containing GHG phase function Legendre coefficients.
OMO	Approximate $\tilde{\omega}_0$ .
PA	Array of temporary values needed in subroutine GUSSTX.
PHASEO	GHG phase function at zero degrees.
PL	Array containing Legendre polynomials.
PSUM	Array containing true phase function at zero degrees; PSUM(1).
RHS	$.5 \tilde{\omega}_2 / \tilde{\omega}_0.$
SUM	integrated GHG phase function.
TRUEG	Asymmetry factor = $\tilde{\omega}_1 / (3\tilde{\omega}_0).$
W	Array containing weights for Gauss-Legendre integration.

#### SUBROUTINE GUSSTX

This subroutine is essentially the same as GUSET: please see GUSET for details.

#### SUBROUTINE PRINTX

Subroutine PRINTX prints out various quantities for the analytic GHG phase function. It will also punch out the Legendre coefficients for the GHG function.

<u>SYMBOL</u>	<u>Explanation or Definition</u>
COEFS	Array containing GHG Legendre coefficients.
EMU	Array containing cosine of Gauss-Legendre angles.
ERROR	Percent error in the GHG integrated phase function.
G	Asymmetry factor; $\tilde{\omega}_1 / (3\tilde{\omega}_0)$ .
NUNIT	Auxiliary unit for writing (punching) GHG Legendre coefficients.
PHASE	GHG phase function at zero degrees.
PHFN	GHG phase function.
PSUM	Array containing true phase function at zero degrees.
SUM	GHG integrated phase function.

## USERS MANUAL FOR AGAUSX

### INPUT DATA

There are nominally four data and control cards required for running program AGAUSX.

<u>CARD</u>	<u>General Description</u>
I	A set of integers which select certain options available within the program.
IA	A user set of supplied angles.
II	A set of data describing the parameters of the particular size distribution function to be used. For cases other than the user-supplied "arbitrary" distribution (IDSTP = 0), only one card of this type is needed.
IIIA	A set of data describing the initial wavelength ( $\mu\text{m}$ ) to be used, its increment, aerosol number density (particles per cc), relative humidity (percent), atmospheric temperature (degrees centigrade), and the desired convergence testing level.
IIIB	If the looping option for relative humidity is invoked then NWAVE-1 cards containing relative humidity and atmospheric temperature must be added.
IV	A set of data describing the optical and physical properties of the aerosol material. If the aerosol is a mixture of materials of unlike properties (NINDX > 1), more than one card of this type is needed for each card of type III. No card of this type is used, however, for runs with parameter IDSTP equal to 6.

Remarks:

1. The simplest type of run (IDSTP=6, water cloud or fog model) requires one card each of types I, II, and III. For other IDSTP choices, at least one card of type IV is also needed.

2. If the run is to use several wavelengths (NWAVE > 1), then at least one card of type IV is required for each wavelength (more than one type IV card will be needed at each wavelength if the aerosol is a multicomponent mixture - NINDX > 1).

3. Two special "looping" modes of AGAUSX affect the number of cards of type III which are needed:

a. For runs at constant relative humidity and several wavelengths, only one type III card is permitted. To activate this mode, the wavelength increment DWAVE on card type III must be larger than  $10^{-4}$ .

b. Runs at constant wavelength and a set of differing values of relative humidity require one card of types IIIA and IV for the first value of relative humidity; subsequently NWAVE-1 cards of types IIIB and IV are needed for each additional value of relative humidity. This option is invoked by setting the parameter "DWAVE" less than  $10^{-4}$  on the first card of type IIIA.

Description of Types of Distributions

<u>IDSTP</u>	<u>DESCRIPTION</u>
0	This is an arbitrary user-supplied distribution. 'NRADI' + 1 cards will be read; the first card contains RLO and DELLR ( $\mu\text{m}$ ). The rest of the cards carry the values of F(J) and must be in order of increasing radius value.
1	This is the zero-order log-normal distribution: the distribution function is given by

$$F(R) = \frac{1}{\sqrt{2\pi} \log_e(\sigma) R} \exp\left\{-\frac{1}{2} \left[\frac{\log_e(R/\bar{R})}{\log_e(\sigma)}\right]^2\right\}.$$

$R \equiv \bar{R}$ ;  $\sigma \equiv \text{SIGMA}$ , is the standard deviation. This distribution type requires one input data card to read in the values of  $\bar{R}$ ,  $\sigma$ ,  $RLO$  and  $RHI$ .

- 2 This is called the double exponential distribution and its distribution function is given by  $F(R) = QA \exp(-AR) + (1-Q)B \exp(-BR)$ .  $Q \equiv \text{CUE}$ . This distribution type requires one input data card to read in the values of  $RLO$ ,  $RHI$ ,  $Q$ ,  $A$ , and  $B$ .  $Q$  is dimensionless while  $A$  and  $B$  have units of  $\mu\text{m}^{-1}$ .

- 3 This model (Deirmendjian's "Model C") does not require any input data card. It carries fixed value of  $\text{DENS}$ ,  $RLO$ , and  $\text{DELRD}$ .  $RHI$  is determined by the input parameter  $\text{NRADI}$ .

$$\begin{aligned} F(R) &= 450.2 & R &\leq .08 \\ &= 2.251 \cdot \text{DELRD} \cdot R^{-4} & R &\geq .08 \end{aligned}$$

- 4 The distribution function of this model (Junge distribution) is given by  $F(R) = QR^{-A}$ ,  $Q \equiv \text{CUE}$ . This distribution type requires one input data card to read in  $RLO$ ,  $RHI$ ,  $A$ ,  $A$ .

- 5 The distribution function for the Modified Gamma/Generalized Khirgian-Mazin distribution is

$$F(R) = R^\alpha \exp \left[ -\left(\frac{R}{R_c}\right)^\gamma \cdot \frac{\alpha}{\gamma} \right], \quad \alpha \equiv \text{ALF}, \quad \gamma \equiv \text{GAM}, \quad \text{and}$$

$R_c \equiv RC$ . One input card is needed to read in RLO, RHI, RC, ALF, GAM, and ELWC. ELWC is not needed for type 5 distribution and therefore can be left blank.

- 6 The size distribution model (NMSU Fog or Cloud Model) is very similar to type 5, except that the user must supply one additional input parameter--namely, the liquid water content (ELWC) in gm/cc. This model can be used for treating situations involving liquid water aerosols like clouds or fogs. For type 6 runs one does not need to read in the values of EMA, CAYA, RHOA, CONC.
- 7 This distribution is essentially same as Junge's distribution (type 4) except that it has fixed parameters. One input card is needed to read in VIS (visibility in km); VIS is used in calculating DENS.
- 8 This is a fixed parameter Continental Bi-modal Model. It does not require an input data card.
- 9 This is a fixed parameter Maritime Bi-modal Model. It does not require an input data card.
- 10 This is a fixed parameter Urban Bi-modal Model. It does not require an input data card.
- 11 This is a user-supplied Bi-modal Model. This requires one input card to read in FOA, FOC, SGA, SGC, RBARA, RBARC. Types 8, 9, 10, and 11 use the sum of two log-normal distributions:

$$F(R) = \sum_{i=1}^2 \frac{N_i}{\sqrt{2\pi} \log_e(\sigma_i) R} \exp \left\{ -\frac{1}{2} \frac{\log_e(R/\bar{R}_i)^2}{\log_e(\sigma_i)} \right\}$$

$N_1 \equiv FOA$ ,  $\bar{R}_1 \equiv RBARA$ ,  $\sigma_1 \equiv SGA$  with similar meaning for  $N_2$ ,  $\bar{R}_2$ , and  $\sigma_2$ . Note that in Type 8, 9, 10 the values of SGA and SGC are  $\log_e(\sigma)$ .



This model (Marshall-Palmer Rain Model) is a simple exponential model which assumes an empirical relationship between rain rate and droplet size distribution parameters:

$$F(D) = N_0 \exp(-\Lambda D).$$

$N_0 = 0.08 \text{ cm}^{-4}$ , and  $\Lambda = 41(\text{RN})^{-0.21}$  in which  $\text{RN} = \text{RAIN}$  is the rain rate in mm/hour. Diameter  $D$  is in cm. The corresponding size distribution function of radius  $R$  is given by

$$F(R) = 2N_0 \exp(-2\Lambda R).$$

This distribution requires one input data card to read in RAIN. The values of  $\text{RLO}$  and  $\text{RHI}$  are fixed at 0 and 0.5 cm respectively. Due to the limitations on the range of Mie-sizes (subroutine MIEGX) type 12 usage is limited to wavelengths of the order of 1 mm or larger. Since subroutine WATER does not contain optical data for wavelengths longer than 0.2 mm, type 12 runs require the user to supply the values of  $\text{EMA}$ ,  $\text{CAYA}$ , and  $\text{RHOA}$  as if rain were a non-aqueous aerosol.

## SUMMARY OF DATA CARD REQUIREMENTS

### CARD TYPE

### INPUT SYMBOLS

I

Integer control parameters: NWAVE, NINDX, IW, IDSTP,  
NRADI, IT, IANG, NCRDS, ITOT, MQRTE, IAPX, FORMAT (1215).

NWAVE: is the number of wavelengths, or relative humidity  
values to be treated in this run. See comments circa read  
of WAVE, DWAVE, etc.

NINDX: is the number of aerosol components which will have  
different optical constants, mass densities or mass concentrations.

IW: = 0 will set the refractive index of the dry aerosol equal  
to that of water at the input wavelength and temperature - see  
Card 4, EMA, CAYA.

IDSTP: Identifies type of aerosol size distribution to be used.

NRADI: Number of particle radii to be expected for IDSTP = 0 or  
3: the input value of NRADI is ignored for IDSTP not zero or 3.  
NRADI must be less than 513.

IT: is the number of Gauss-Legendre angles (order of expansion)  
if IANG = 0 or number of angles between 0 degrees and 180 degrees  
if IANG = 1. If only extinction coefficients, etc. are desired,  
i.e., not phase functions, then set -IT- equal to one.

IANG: = 0 for computations of phase function at -IT- Gauss-  
Legendre quadrature angles: no scattering fractions will be  
printed. IANG = 1 for computations of scattering fractions and  
phase functions at -IT- equally spaced angles between 0 and  
180 degrees. IANG = 2 will allow -IT- user supplied angles to  
be read - FORMAT (16F5.1). This requires at least one card of  
type IA.

CARD  
TYPE

INPUT SYMBOLS

---

- I      NCRDS: = 1 write/punch Legendre coefficients and order of expansion on NUNIT - FORMAT (D25.14,1X,15): = 2 write/punch scattering fractions, phase functions, cosines and counter on NUNIT - FORMAT (3(D12.61X),15): = 3 write/punch both scattering fractions, phase functions, cosines, counter, and Legendre coefficients and order of expansion on NUNIT - FORMATS (3(D12.6.,1X),15) and (D25.14,1X,15): scattering fractions, phase functions, cosines and counter (respectively) are always written/punched before the Legendre coefficients and order of expansion (respectively).
- ITOT: Works in conjunction with NCRDS and NWAVE to write/punch either individual wavelength values or averaged wavelength values or both on NUNIT: = 1 for individual wavelengths; = 2 for averaged wavelengths; = 3 for both.
- NUNIT: defines device number. See previous comment card.
- MQRTE: = 12345 will cause prints of Mie efficiency factors at every value of particle radius used in the Mie calculations; set MQRTE = 0 if such prints are not desired.
- IAPX: if GT zero the GHG (analytic) phase function will be constructed at IAPX Gauss-Legendre angles (order of expansion).
- IA      User supplied set of -IT- angles FORMAT (16F5.1) 16 values per card, more than 1 card may be needed. This card is only needed when IANG = 2.

CARD  
TYPE

INPUT SYMBOL

---

II      Distribution parameters: only one type per run.    FORMAT (6E12.6).  
For a more detailed description of these parameters see the previous  
discussions in AGXPT1. All units are in micrometers.

TYPE 0.    USER SUPPLIED - NRADI + 1 CARDS

          RLO, DELLR

          FF(I), I = 1, NRADI

TYPE 1.    LOG-NORMAL

          RBAR, SIGMA, RLO, RHI

TYPE 2.    DOUBLE EXPONENTIAL

          RLO, RHI, CUE, A, B

TYPE 3.    DEIRMENDJIAN MODEL C

          - NO INPUT -

TYPE 4.    POWER LAW (JUNGE)

          RLO, RHI, CUE, A

TYPE 5.    MODIFIED GAMMA

          RLO, RHI, RC, ALF, GAM, ELWC

TYPE 6.    MODIFIED GAMMA FOG MODEL

          RLO, RHI, RC, ALG, GAM, ELWC

TYPE 7.    POWER LAW

          VIS

TYPE 8.    CONTINENTAL BIMODAL

          - NO INPUT -

TYPE 9.    MARITIME BIMODAL

          - NO INPUT -

CARD  
TYPE

INPUT SYMBOLS

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- II      TYPE 10.    URBAN BIMODAL
- NO INPUT -
- TYPE 11.    USER SUPPLIED BIMODAL
- FOA, RBARA, GSA, FOC, RBARC, SGC
- TYPE 12.    MARSHALL-PALMER RAIN MODEL
- RAIN
- III     Control Parameters:    FORMAT (6E12.6) WAVE, DWAVE, RELHUM,  
         DENS, TEMP, DELTA.    For looping over different values of  
         relative humidity set DWAVE = 0, and add NWAVE - 1 cards  
         containing RELHUM and TEMP.    FORMAT (2E12.6).
- WAVE:    is wavelength in micrometers
- DWAVE:    is the wavelength increment in micrometers.    If  
         DWAVE is less than 1.E-4, a special case applies used for  
         looping over NWAVE values of RELHUM.    For example in that  
         case a card which carries the value of RELHUM and TEMP must  
         be repeated NWAVE - 1 times; the first card of this type  
         must contain WAVE, DWAVE, RELHUM, DENS, TEMP and DELTA.
- RELHUM:    is relative humidity in percent.
- DENS:    is particle number per cubic centimeter.    User-supplied  
         value of DENS will be ignored for IDSTP = 3 or greater than  
         6 because those distributions carry pre-determined density  
         values.    Also, if DENS is less than 1E-4, the particle number  
         density will be calculated from mass densities and mass  
         concentrations.

CARD  
TYPE

INPUT SYMBOLS

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III      TEMP: is the temperature of the atmosphere in degrees C.  
DELTA: is the convergence criterion. Within a particular  
         size range interval, halving is terminated when the quantity  
         DEL is less than DELTA.

IV      Optical and physical data (Read in AGXPT2) FORMAT (4F10.6E15.7)  
EMA, CAYA, EMUA, RHOA, CONC.  
EMA: is the real part of the index of refraction of dry aerosol.  
CAYA: is the imaginary part of refractive index for dry aerosol.  
CAYA is assumed to be negative: do not enter CAYA with a  
negative sign.  
EMUA: is Hanel's growth factor (ME-BAR)/accretion coefficient.  
RHOA: is the mass density (sp. GRAV) of dry aerosol.  
CONC: is the mass concentration (GM/CC) of dry aerosol.  
For looping over wavelength or relative humidity repeat this  
card NWAVE times and interleave with card 3: For looping over  
aerosol components also repeat nindx times. This card is not  
needed when IDSTP = 6. Also if IW = 0 EMA and CAYA will  
internally be set equal to the refractive index of water and  
therefore may be left blank: values for EMUA, RHOA, and CONC  
may be necessary to supply, depending upon the users needs.

Remarks:

1. Card Type IV is not required and is never read-in if IDSTP = 6  
(water cloud/for model) since the relevant data are obtained from subroutine  
WATER.

2. In the case IDSTP = 12, the rain model, card type IV must carry  
the optical data for liquid water as EMA and CAYA. The reason for that  
inconsistency is that the rain model will most likely be useable at

wavelengths for which no data appear in subroutine WATER (restricted to  $\lambda \leq 0.2\text{mm}$ ). [The large droplet sizes to be found in the rain model will usually cause premature failure of the Mie routine at small wavelengths.]

3. Card type IV, with appropriately adjusted data values, must be repeated (NWAVE - 1) times.

4. EMA and CAYA may be left blank on Card type 4 when IW = 0 as they will internally be set equal to the value for water.

#### Incidental Remarks Regarding AGAUSX

(1) In AGAUSX, the average "dry volume per particle" is found using all available values for particle radii. It may differ from that printed in routine AGXPT2 since that routine might not proceed to the use of all available values.

(2) The "volume" convergence tests in AGXPT2 use the volume inferred after any growth arising from non-zero saturation ratios has been included.

(3) It should be noted that the convergence tests used in AGAUSX do not really provide tests of the absolute accuracies achieved for the tested quantity. It is possible for "exit" to occur ( $\delta < \Delta$ ) even though the use of "another" halving might lead to  $\delta > \Delta$  again. If runs using some choice of  $\Delta$  might lead to what appear to be "unusual" or unexpected results, it is advised that, as a test, the case be re-run using a smaller value of  $\Delta$ .

(4) Some users may wish to explore possible increases in computation efficiency which might result from changes in the number (NI) of size-intervals, or, the ways in which they have been chosen (in AGXPT1).

### Comments on Usage of AGAUSX in the IANG = 0 Mode

AGAUSX has been coded to preserve the option of creating the expansion coefficients,  $\tilde{\omega}_\ell$ , which are needed by the multiple scattering codes STAR04, AGSCAT, and the thermal emission code CLEM70(8). Usage of the  $\tilde{\omega}_\ell$  coefficients for the above purposes, however, requires some caution on the part of the user. In particular, users must not assume that the absence of abnormal termination of runs of AGAUSX guarantees that "all is well". Past experience has shown that "warnings" of possible problems printed by those programs may not be noticed or taken very seriously. In an attempt to overcome those oversights, additional tests and warnings have been incorporated in AGAUSX. If those warnings are to be meaningful, users should examine printed outputs carefully for such warnings before using the results of runs as inputs to subsequent codes.

One particular point which should be checked is to see that the quantity printed under the heading ALBDO agrees reasonably well with the zeroth coefficient ( $\tilde{\omega}_0$ ) of the expansion coefficients. Substantial disagreement between those two quantities usually means that the parameter "IT" used in a run was too small to achieve a really accurate reconstruction of the phase function from only "IT" Legendre expansion terms.

Should possible inaccuracies be found, please contact R. C. Shirkey, Atmospheric Sciences Laboratory, White Sands Missile Range, New Mexico 88002 .



## SAMPLES OF INPUT AND OUTPUT FOR AGAUSX

### INPUT

The subsequent output section is based upon the following input.

Example 1: IDSTP = 0 (User supplied distribution data)

Column 5

2	1	9	0	11	5	0	0	0	012345	0
---	---	---	---	----	---	---	---	---	--------	---

0.10000E-00 0.0200E+00

0.00000E-00

0.20000E-00

0.40000E-00

0.60000E-00

0.80000E-00

1.00000E-00

0.80000E-00

0.60000E-00

0.40000E-00

0.20000E-00

0.00000E-00

10.6000E+00 0.10000E-05 00.0000E+00 0.00000E-05 25.0000E+00 1.00000E-02

1.9530 .46800 0.00000 1.87000 1.000000E-09

75.0000E+00 25.0000E+00

1.9530 .468000 0.15900 1.87000 1.000000E-09

This example is set up to read 11 distribution data cards, and to run for two values of relative humidity at  $\lambda = 10.6\mu\text{m}$ . Since MQRTE = 12345, detailed Mie results for each of the 11 radii will be printed. Parameter 'IT' is 5, IANG = 1. Note that the second data card contains RLO (= 0.1 $\mu\text{m}$ ) and DELLR (= 0.02). The next eleven cards contain F(RLO), F(RLO + DELLR, etc.). The remaining cards consist of two pairs of cards, two for each of the two values of NWAVE. In all cases, DENSH is zero which means that particle number densities will be calculated from RHOA (1.87, above), CONC ( $10^{-9}$  gm/cc, above) and the average particle volume computed within the program.

Example 2: IDSTP = 1 (Log normal distribution)

Column 5



1    3    9    5    4    5    0    0    0    0    0    0

3.70000E-01 1.54000E+00 0.00500E-00 1.00000E-00

10.6000E+00 0.10000E-05 00.0000E+00 0.00000E-05 25.0000E+00 1.00000E-02

1.9530    .468000    0.00000    1.87000    1.000000E-09

0.15900    1.87000    1.000000E-09

0.15600    1.87000    1.000000E-09

Remarks: The second card carries RBAR, SIGMA, RLO and RHI. If RLO and RHI are set to zero, the program itself will choose RLO and RHI. Particle number density will also be calculated from mass density and concentration.

Example 3: IDSTP = 3 (Deirmendjian's Model C)

Column 5



2 1 0 3 100 5 0 0 0 0 0 0

10.6000E+00 0.10000E-05 00.0000E+00 0.00000E-05 25.0000E+00 1.00000E-02

0.0000 .000000 0.00000 1.87000 1.0000000-09

75.00000+00 25.00000+00

0.0000 .000000 0.15900 1.87000 1.0000000-09

Remarks: 100 values of radii will be used for 2 values of relative humidity with different growth factors. Particle density will be calculated from mass density and concentration. Since IW = 0, the aerosol component is considered to be pure water; i.e., EMA and CAYA will be set equal to the values for water.

Example 4: IDSTP = 5 (Modified gamma distribution)

Column 5



1 2 9 5 40 1 0 0 0 0 0 0

.0278520+00 1.225490+01 4.000000+00 .6000000+01 .1000000+01

.7000000+00 .0000000-04 .0000000+00 1.000000+02 5.000000+00 1.000000-02

1.3300 .000000 0.00000 1.00000 1.0000000+00

1.4300 .000000 0.00000 1.00000 1.0000000-01

Remarks: This example sets NINDX = Z, and treats a mixture of two aerosol components having different refractive indices and mass concentrations.

Example 5: IDSTP = 7 (Power Law)

Column 5



1 1 0 7 0 1 1 3 1 23 0 8

+6.000000+00

10.60000+00 .0000000+00 .0000000+00 .1000000+03 25.00000+00 1.000000-02

0.0000 .000000 0.00000 0.00000 0.0000000+00

Remarks: The GHG analytic phase function will be constructed at eight

Gauss-Legendre angles (IAPX = 8) for pure water (IW = 0). Scattering fractions (not computed), phase functions, cosines, a counter, and Legendre coefficients will be written on unit 23 for individual wavelengths only.

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 \*\*\* PROGRAM AGAUX \*\*\*  
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INTEGER CONTROL PARAMETERS: NWAVE NINDX IW IDSTP NRADI IT IANG NCRDS ITOT NUNIT MORTE IAPX  
 2 1 9 0 11 5 0 0 0 4 12345 0

AEROSOL PARAMETERS ARE

RADIUS	RELATIVE NO.	RADIUS	RELATIVE NO.	RADIUS	RELATIVE NO.	RADIUS	RELATIVE NO.	RADIUS	RELATIVE NO.
1.000000-001	.000000	2.000000-001	2.000000-001	1.400000-001	4.000000-001	1.600000-001	6.000000-001	1.800000-001	8.000000-001
2.000000-001	1.000000+000	2.200000-001	8.000000-001	2.400000-001	6.000000-001	2.600000-001	4.000000-001	2.800000-001	2.000000-001
3.000000-001	.000000								

NORMALIZATION FACTOR FOR SIZE DISTRIBUTION = .9999988-001  
 AVERAGE NUMERICAL DRY VOLUME IS 3.769914-002 CUBIC MICROMETERS

SIZE-INTERVALS USED ARE AS FOLLOWS

INTERVAL NO. 1 RMIN = .10000 RMAX = .30000  
 INPUT PARAMETERS

WAVE = .106000+002 MICRONS  
 DWAVE = .100000-005 MICRONS  
 RELHUM = .000000 PERCENT  
 DENS = .000000 PARTICLES/CC  
 TEMP = .250000+002 DEG C  
 DELTA (CONVERGENCE CRITERION) = .100000-001

RELATIVE HUMIDITY OPTION IN EFFECT FOR 2 VALUES

\*\*\* PARTICLE NUMBER DENSITY WILL BE CALCULATED FROM MASS DENSITY AND MASS CONCENTRATION \*\*\*

RELATIVE HUMIDITY FOR THIS RUN = .00 PERCENT. WAVELENGTH = 10.600 MICRONS  
 INDEX OF REFRACTION FOR PURE WATER IS: 1.178200 - .0756201

MASS DENSITY OF WATER AT 25.00 DEG C IS: 1.00 GM/CC  
 INDX= 1 M= 1.953000 K = -.4680001. MASS DENSITY = 1.870000 GROWTH FACTOR = .0000. CONC = 1.00000-009 GM/CC

R(MICRONS)	DRY	RADIUS	N(R)	MIE	SIZE	Q (EXT)	Q (SCA)	Q (RADAR)
10000	1.00000-001	.00000	5.92753-002	3.76803-002	9.58810-006	1.43542-005		
20000	3.00000-001	7.45059-008	1.77826-001	1.17142-001	7.84951-004	1.15695-003		
30000	2.00000-001	1.00000+001	1.18551-001	7.63388-002	1.54047-004	2.29277-004		
40000	1.50000-001	5.00001+000	8.89130-002	5.68193-002	4.86250-005	7.26187-005		
50000	2.50000-001	5.00001+000	1.48188-001	9.63911-002	3.77213-004	5.58973-004		
60000	1.25000-001	2.50000+000	7.40942-002	4.72113-002	2.34271-005	3.50339-005		
70000	1.75000-001	7.50001+000	1.03732-001	6.65223-002	9.01846-005	1.34473-004		
80000	2.25000-001	7.50001+000	1.33369-001	8.62883-002	2.47104-004	3.67016-004		

27500 2.75000-001 2.50000-000 1.63007-001 1.06668-001 5.53216-004 8.17687-004  
 11250 1.12500-001 1.25000-000 6.66847-002 4.24372-002 1.53641-005 2.29894-005  
 13750 1.37500-001 3.75000-000 8.15036-002 5.20046-002 3.43153-005 5.12839-005  
 16250 1.62500-001 6.25001-000 9.63224-002 6.16578-002 6.70104-005 1.00000-004  
 18750 1.87500-001 8.75001-000 1.11141-001 7.14152-002 1.88920-004 1.77162-004  
 21250 2.12500-001 8.75001-000 1.25960-001 8.12957-002 1.96458-004 2.92106-004  
 23750 2.37500-001 6.25001-000 1.40779-001 9.13193-002 3.06998-004 4.55464-004  
 26250 2.62500-001 3.75000-000 1.55598-001 1.01507-001 4.58887-004 6.79152-004  
 28750 2.87500-001 1.25000-000 1.70417-001 1.11879-001 6.61463-004 9.76341-004  
 FOR COMPONENT NO. 1: VPFF = 5.33832-010 MASS CONCENTRATION = 9.98266-010 GM/CC. KEXT = 1.53581-001 PER KM  
 FOR COMPONENT NO. 1: VPFF = 5.33832-010 MASS CONCENTRATION = 9.98266-010 GM/CC. KEXT = 1.53581-001 PER KM

TOTAL NUMBER OF RADII USED WAS 17  
 ATTENUATION COEF. = 1.53581-004 SQ-METERS/MILLIGRAM OF DRY AEROSOL MATERIAL  
 DISTRIBUTION WAVELENGTH REFRACTIVE EXTINCTION X SECTION SCATTERING X SECTION ALBDO  
 TYPE (MICRONS) INDEX (SQ MICRONS) (SQ MICRONS)  
 0 10-6000  
 K(EXT) = 1.5358138-001; K(SCA) = 4.6128525-004; K(RAD) = 6.8411013-004 ALL PER KM

WAVENUMBER = 9.433962+002 CM-1 DENSITY = 1.418492+004 PARTICLES PER CC  
 MU PHASE FUNCTION MU PHASE FUNCTION MU PHASE FUNCTION MU PHASE FUNCTION  
 .906179860 .4146052001-002 .538469315 .2926897054-002 .000000000 .2252592763-002 -.538469315 .2884668502-002  
 -.906179853 .4058968159-002

L L-TH COEFFICIENT RMS DEVIATION  
 0 3.003523219376802-003 7.750136210233904-004  
 1 4.436977906152606-005 7.744139511487447-004  
 2 1.501870749052614-003 2.744990281292101-006  
 3 6.654647222603671-006 4.267161513027418-009

\*\*\*\*\* END OF RELATIVE HUMIDITY CYCLE NUMBER 1 \*\*\*\*\*

RELATIVE HUMIDITY FOR THIS RUN = 75.00 PERCENT. WAVELENGTH = 10.600 MICRONS  
 INDEX OF REFRACTION FOR PURE WATER IS: 1.178200 - .0756201  
 MASS DENSITY OF WATER AT 25.00 DEG C IS: 1.00 GM/CC  
 INDX = 1.953000 K = -.1680001. MASS DENSITY = 1.870000 GROWTH FACTOR = .1590. CONC = 1.00000-009 GM/CC

R(MICRONS) DRY RADIUS (NIR) MIE SIZE Q (EXT) Q (SCA) Q (RADAR)

#12118 1.00000-001 .00000 7.45059-008 7.18307-002 3.78534-002 9.96307-006 1.49074-005  
 #36866 3.00000-001 7.45059-008 2.18525-001 1.19070-001 8.57504-004 1.25688-003  
 #24492 2.00000-001 1.00000-001 1.45178-001 7.74352-002 1.66587-004 2.47356-004  
 #18305 1.50000-001 5.00001+000 1.08504-001 5.74620-002 4.80194-005 7.74377-005  
 #30679 2.50000-001 5.00001+000 1.81852-001 9.79190-002 4.80660-004 6.06222-004  
 #15212 1.25000-001 2.50000+000 9.01675-002 4.76208-002 2.47475-005 3.69759-005  
 #21399 1.75000-001 7.50001+000 1.26841-001 6.73942-002 9.70107-005 1.44390-004  
 #27586 2.25000-001 7.50001+000 1.63515-001 8.76038-002 2.68255-004 3.97217-004  
 #33773 2.75000-001 2.50000+000 2.00189-001 1.08401-001 6.03497-004 8.87871-004  
 #13645 1.12500-001 1.25000+000 8.05991-002 4.27289-002 1.61124-005 2.40921-005  
 #16758 1.37500-001 3.75000+000 9.93359-002 5.25311-002 3.64635-005 5.44353-005  
 #19852 1.62500-001 6.25001+000 1.17673-001 6.24156-002 7.88390-005 1.07040-004  
 #22945 1.87500-001 8.75001+000 1.36010-001 7.23999-002 1.28287-004 1.90719-004  
 #26039 2.12500-001 8.75001+000 1.54346-001 8.25024-002 2.82894-004 3.15686-004  
 #29132 2.37500-001 6.25001+000 1.72683-001 9.27418-002 3.33784-004 4.93512-004  
 #32226 2.62500-001 3.75000+000 1.91020-001 1.03138-001 5.00128-004 7.37074-004  
 #35319 2.87500-001 1.25000+000 2.09357-001 1.13711-001 7.22142-004 1.06049-003  
 FOR COMPONENT NO. 1 INTERVAL NO. 1 17 RADII WERE USED. CONTRIBUTION TO CTSUM = 1.650363-002  
 FOR COMPONENT NO. 1 : VPF = 9.82639-010 MASS CONCENTRATION = 1.43246-009 GM/CC. KEXT = 2.34102-001 PER KM

TOTAL NUMBER OF RADII USED WAS 17  
 ATTENUATION COEF. = 2.34102-004 SQ-METERS/MILLIGRAM OF DRY AEROSOL MATERIAL  
 ATTENUATION COEF. = 1.63426-004 SQ-METERS/MILLIGRAM OF WET AEROSOL MATERIAL

DISTRIBUTION TYPE	WAVELENGTH (MICRONS)	REFRACTIVE INDEX	EXTINCTION X SECTION (SQ MICRONS)	SCATTERING X SECTION (SQ MICRONS)	ALBDO
0	10.6000	1.58711 - .17811	1.65036087855697-002	5.31542978029336-005	3.22076815064065-003
K(EXT)	= 2.3410243-001	K(SCA) = 7.5398964-004	K(RAD) = 1.1142163-003	ALL PER KM	

WAVENUMBER = 9.433962+002 CM-1 DENSITY = 1.418492+004 PARTICLES PER CC

PHASE FUNCTION (INTEGRAL NORMALIZED TO 4 PI OMEGA ZERO)				RMS DEVIATION	
MU	PHASE FUNCTION	MU	PHASE FUNCTION	MU	PHASE FUNCTION
.906179860	.4459963704-002	.538469315	.3144036687-002	.000000000	.2415478462-002
-.906179853	.4338685889-002				

L-TH COEFFICIENT		RMS DEVIATION	
L	COEFFICIENT	MU	PHASE FUNCTION
0	3.220767830498517-003	8.315518498420715-004	
1	6.07715806895867-005	8.304896036861464-004	
2	1.610604202141985-003	4.579665130677313-006	
3	1.110328958020546-005	1.081949518866310-008	
4	3.374043444637209-008	6.380313707921026-010	

SUMMARY OF RESULTS FOR THIS RUN ARE AS FOLLOWS :  
 END OF RELATIVE HUMIDITY CYCLE NUMBER 2

WAVELENGTH (MICROMETERS)	REL. HUMIDITY (PERCENT)	AEROSOL MASS (GM/150.CM-KM)	K(EXTINCTION) (PER KM)
10.600000	.000000	9.98266-005	1.53581-001
10.600000	75.000000	1.43246-004	2.34102-001

RESULTS AVERAGED OVER PARAMETER NWAVE FOLLOW

EXTINCTION COEF. = 9.93842-001 (PER KM)

SCATTERING COEF. = 6.07637-004 (PER KM)

BACK-SCATTERING COEF. = 8.99163-004 (PER KM)

ATTENUATION COEF. = 8.93842-004 SQ-METERS/MG

MU	PHASE FUNCTION	MU	PHASE FUNCTION	MU	PHASE FUNCTION	MU	PHASE FUNCTION
.906179860	.4303007852-002	.538469315	.3035466856-002	.000000000	.2334035613-002	-.538469315	.2986260195-002
-.906179853	.4198827024-002						

L	L-TH COEFFICIENT	RMS	DEVIATION
0	3.1112145554041490-003	8.032697587623261-004	
1	5.257347947917879-005	8.024513663258404-004	
2	1.556237490149215-003	3.662256204961523-006	
3	8.878974767867476-006	7.527153123021435-009	
4	2.336128090973943-008	5.581565348800055-010	



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 \*\*\*  
 \*\*\* PROGRAM AGAUSX \*\*\*  
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INTEGER CONTROL PARAMETERS: N WAVE NINDEX IW IDSTP NRADI IT IANG NCRDS ITOT NUNIT MQRTE IAPX  
 1 1 9 1 100 5 0 0 0 4 0 0

AEROSOL PARAMETERS ARE RBAR= .370000+000 SIGMA= .154000+001 RLO = .500000-002 RHI = .100000+001

NORMALIZATION FACTOR FOR SIZE DISTRIBUTION = .9893521+000

AVERAGE ANALYTIC DRY VOLUME PER PARTICLE IS 4.909649-001 CUBIC MICROMETERS  
 AVERAGE NUMERICAL DRY VOLUME IS 4.183917-001 CUBIC MICROMETERS

SIZE-INTERVALS USED ARE AS FOLLOWS

INTERVAL NO. 1	RMIN =	.00500	RMAX =	.37000
INTERVAL NO. 2	RMIN =	.37000	RMAX =	1.00000
INPUT PARAMETERS				
WAVE =	.106000+002	MICRONS		
DWAVE =	.000000	MICRONS		
RELHUM =	.000000	PERCENT		
DENSH =	.060000	PARTICLES/CC		
TEMP =	.250000+002	DEG C		
DELTA (CONVERGENCE CRITERION) = .100000-001				

\*\*\* PARTICLE NUMBER DENSITY WILL BE CALCULATED FROM MASS DENSITY AND MASS CONCENTRATION \*\*\*

RELATIVE HUMIDITY FOR THIS RUN = .00 PERCENT. WAVELENGTH = 10.600 MICRONS  
 INDEX OF REFRACTION FOR PURE WATER IS: 1.178200 - .075620I

MASS DENSITY OF WATER AT 25.00 DEG C IS: 1.000 GM/CC  
 INDX= 1 M= 1.953000 K = -.468000I. MASS DENSITY = 1.870000 GROWTH FACTOR = .0000. CONC = 1.000000-009 GM/CC  
 FOR COMPONENT NO. 1 INTERVAL NO. 1 17 RADII WERE USED. CONTRIBUTION TO CTSUM = 1.426828-002  
 FOR COMPONENT NO. 2 INTERVAL NO. 2 17 RADII WERE USED. CONTRIBUTION TO CTSUM = 1.294031-001  
 FOR COMPONENT NO. 1 : VPF = 5.34003-010 MASS CONCENTRATION = 9.98586-010 GM/CC. TEXT = 1.835333-001 PER KM

TOTAL NUMBER OF RADII USED WAS 34  
 ATTENUATION COEF. = 1.83533-004 SQ-METERS/MILLIGRAM OF DRY AEROSOL MATERIAL

DISTRIBUTION WAVELENGTH	REFRACTIVE INDEX	EXTINCTION X SECTION	SCATTERING X SECTION
TYPE (MICRONS)	INDEX (SQ MICRONS)		ALBDO
1 10.6000	1.953011 - .23961I	1.43594585359097-001	9.14047565311193-003
K(EXT) = 1.8353269-001I	K(SCA) = 1.1682725-002I	K(RAD) = 1.5537733-002	ALL PER KM

WAVENUMBER = 9.433962+002 CM-1 DENSITY = 1.278131+003 PARTICLES PER CC

PHASE FUNCTION  
(INTEGRAL NORMALIZED TO 4 PI OMEGA ZERO)

MU	PHASE FUNCTION	MU	PHASE FUNCTION	MU	PHASE FUNCTION	MU	PHASE FUNCTION
.906179860	.9663867112-001	.538469315	.6619704887-001	.000000000	.4762377590-001	-.538469315	.5691573909-001
-.906179853	.7764094044-001						

L	L-TH COEFFICIENT	RMS	DEVIATION
0	6.365473195910454-002	1.784613775089383-002	
1	9.706226061098278-003	1.655639195814729-002	
2	3.208455536514521-002	5.789812203147449-004	
3	1.403631700668484-003	9.536886523164867-006	
4	3.018663846887648-005	1.268959048950080-008	

SUMMARY OF RESULTS FOR THIS RUN ARE AS FOLLOWS :

WAVELENGTH (MICROMETERS)	REL. HUMIDITY (PERCENT)	AEROSOL MASS (GM/(SQ.CM-KM))	K (EXTINCTION) (PER KM)
10.600000	.000000	9.98586-005	1.83533-001

\*\*\*\*\*  
 \*\*\* PROGRAM AGAUX \*\*\*  
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INTEGER CONTROL PARAMETERS: NMAVE NINDX IW IDSTP NRADI IT IANG NCRDS ITOT NUNIT MQRTE IAPX  
 2 1 0 3 100 5 0 0 4 0 0

\*\*\* WATER ONLY CASE \*\*\*

AEROSOL PARAMETERS ARE

NORMALIZATION FACTOR FOR SIZE DISTRIBUTION = .1135122+000  
 AVERAGE NUMERICAL DRY VOLUME IS 1.197754-002 CUBIC MICROMETERS

SIZE-INTERVALS USED ARE AS FOLLOWS

INTERVAL NO. 1 RMIN = .02000 RMAX = .10000  
 INTERVAL NO. 2 RMIN = .10000 RMAX = 2.00000  
 INPUT PARAMETERS  
 WAVE = .106000+002 MICRONS  
 DWAVE = .100000-005 MICRONS  
 RELHUM = .000000 PERCENT  
 DENSH = .000000 PARTICLES/CC  
 TEMP = .250000+002 DEG C  
 DELTA (CONVERGENCE CRITERION) = .100000-001  
 RELATIVE HUMIDITY OPTION IN EFFECT FOR 2 VALUES

\*\*\* PARTICLE NUMBER DENSITY WILL BE CALCULATED FROM MASS DENSITY AND MASS CONCENTRATION \*\*\*

RELATIVE HUMIDITY FOR THIS RUN = .00 PERCENT. WAVELENGTH = 10.600 MICRONS  
 INDEX OF REFRACTION FOR PURE WATER IS: 1.178200 - .075620I

MASS DENSITY OF WATER AT 25.00 DEG C IS: 1.00 GM/CC  
 INDX= 1 M= 1.178200 K = - .075620I. MASS DENSITY = 1.870000 GROWTH FACTOR = .0000. CONC = 1.00000-009 GM/CC

FOR COMPONENT NO. 1 INTERVAL NO. 1 17 RADII WERE USED. CONTRIBUTION TO CTSUM = 7.654085-005  
 FOR COMPONENT NO. 1 INTERVAL NO. 2 65 RADII WERE USED. CONTRIBUTION TO CTSUM = 9.724075-004  
 FOR COMPONENT NO. 1: VPF = 1.61669-010 MASS CONCENTRATION = 3.02322-010 GM/CC. KEXT = 1.41262-002 PER KM

TOTAL NUMBER OF RADII USED WAS 82  
 ATTENUATION COEF. = 4.57685-005 SQ-METERS/MILLIGRAM OF DRY AEROSOL MATERIAL

DISTRIBUTION TYPE	WAVELENGTH (MICRONS)	REFRACTIVE INDEX	EXTINCTION X SECTION	SCATTERING X SECTION	ALBDO
3	10.6000	1.1782(1 - .06421I)	1.02512286684942-003	2.84846289559937-005	2.77865510433912-002
K(EXT) = 1.4126193-002		K(SCA) = 3.9251818-004	K(RAD) = 4.0384070-004	ALL PER KM	

WAVENUMBER = 9.433962+002 CM-1 DENSITY = 1.378000+004 PARTICLES PER CC

PHASE FUNCTION  
(INTEGRAL NORMALIZED TO 4 PI OMEGA ZERO)

MU	PHASE FUNCTION	MU	PHASE FUNCTION	MU	PHASE FUNCTION	MU	PHASE FUNCTION
.906179860	.5109181860-001	.538469315	.3195016971-001	.000000000	.202975937-001	-.538469315	.2146602934-001
-.906179853	.2682040236-001						

L	L-TH COEFFICIENT	RMS	DEVIATION
0	2.778654801659286-002	1.14680593956262-002	
1	1.184961145140231-002	7.929413230158389-003	
2	1.517573744058609-002	1.138761916081421-003	
3	2.753715642029420-003	8.331048138643382-005	
4	2.637724683154374-004	6.7029349984836872-009	

\*\*\*\*\* END OF RELATIVE HUMIDITY CYCLE NUMBER 1 \*\*\*\*\*

RELATIVE HUMIDITY FOR THIS RUN = 75.00 PERCENT. WAVELENGTH = 10.600 MICRONS  
INDEX OF REFRACTION FOR PURE WATER IS: 1.178200 - .0756201

MASS DENSITY OF WATER AT 25.00 DEG C IS: 1.00 GM/CC

INDEX = 1 M = 1.178200 K = -.0756201. MASS DENSITY = 1.870000 GROWTH FACTOR = .1590. CONC = 1.00000-009 GM/CC  
FOR COMPONENT NO. 1 INTERVAL NO. 1 17 RADII WERE USED. CONTRIBUTION TO CTSUM = 1.327722-004  
FOR COMPONENT NO. 1 INTERVAL NO. 2 65 RADII WERE USED. CONTRIBUTION TO CTSUM = 1.851981-003  
FOR COMPONENT NO. 1: VPF = 2.98743-010 MASS CONCENTRATION = 4.35500-010 GM/CC. KEXT = 2.67287-002 PER KM

TOTAL NUMBER OF RADII USED WAS 82

ATTENUATION COEF. = 8.66003-005 SQ-METERS/MILLIGRAM OF DRY AEROSOL MATERIAL  
ATTENUATION COEF. = 6.13747-005 SQ-METERS/MILLIGRAM OF WET AEROSOL MATERIAL

DISTRIBUTION	WAVELENGTH	REFRACTIVE	EXTINCTION X SECTION	SCATTERING X SECTION	ALBDO
TYPE	(MICRONS)	INDEX	(SQ MICRONS)	(SQ MICRONS)	
3	10.6000	1.178211 -.064211	1.93967205996159-003	8.68672477736254-005	4447845021262765-002
K(EXT)	2.6728681-002	K(ISA) = 1.1970307-003	K(RAD) = 9.9110602-004	ALL PER KM	

WAVENUMBER = 9.433962+002 CM-1 DENSITY = 1.378000+004 PARTICLES PER CC

PHASE FUNCTION  
(INTEGRAL NORMALIZED TO 4 PI OMEGA ZERO)

MU	PHASE FUNCTION	MU	PHASE FUNCTION	MU	PHASE FUNCTION	MU	PHASE FUNCTION
.906179860	.9468039110-001	.538469315	.5532553978-001	.000000000	.3153885575-001	-.538469315	.3000225802-001
-.906179853	.3528082650-001						

L	L-TH COEFFICIENT	RMS	DEVIATION

2.483143028803170-002  
1.442674698773772-002  
2.890899160140380-003  
3.185206749558135-004  
1.253139425561045-008

4.478449793532491-002  
2.891276823356048-002  
2.72476538084474-002  
6.96483644240063-003  
1.008492516120894-003

0  
1  
2  
3  
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..... END OF RELATIVE HUMIDITY CYCLE NUMBER 2 .....  
SUMMARY OF RESULTS FOR THIS RUN ARE AS FOLLOWS :

WAVELENGTH (MICROMETERS)	REL. HUMIDITY (PERCENT)	AEROSOL MASS (GM/1SQ. CM-KM)	K (EXTINCTION) (PER KM)
10.600000	.000000	3.02322-005	1.41262-002
10.600000	75.000000	4.35500-005	2.67287-002

RESULTS AVERAGED OVER PARAMETER NWAIVE FOLLOW

EXTINCTION COEF. = 2.04274-002 (PER KM)  
SCATTERING COEF. = 7.94774-004 (PER KM)  
BACK-SCATTERING COEF. = 6.97473-004 (PER KM)  
ATTENUATION COEF. = 6.61844-005 SQ-METERS/MG

PHASE FUNCTION

MU	PHASE FUNCTION	MU	PHASE FUNCTION	MU	PHASE FUNCTION
----	----------------	----	----------------	----	----------------

.906179860 .7287610415-001  
-.906179853 .3105061431-001

L	L-TH COEFFICIENT	RMS	DEVIATION
0	3.628552239388227-002	1.810604403726757-002	
1	2.039118949323893-002	1.117380033247173-002	
2	2.121169539168477-002	2.01414712499073-003	
3	4.859276057686657-003	2.009153358812910-004	
4	6.361324922181666-004	9.650542254213690-009	

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INTEGER CONTROL PARAMETERS: NWAVE NINDX IW IDSTP NRADI IT IANG NCRDS ITOT NUNIT MQRTE IAPX

AEROSOL PARAMETERS ARE RLO= .2785-001 RH1= .1225+002 RC= .4000+001 ALF= .6000+001 GAM= .1000+001

NORMALIZATION FACTOR FOR SIZE DISTRIBUTION = .4210611+002

AVERAGE ANALYTIC DRY VOLUME PER PARTICLE IS 6.255275+002 CUBIC MICROMETERS  
 AVERAGE NUMERICAL DRY VOLUME IS 6.182091+002 CUBIC MICROMETERS

SIZE-INTERVALS USED ARE AS FOLLOWS

INTERVAL NO. 1 RMIN = .02785 RMAX = 4.00000  
 INTERVAL NO. 2 RMIN = 4.00000 RMAX = 12.25490

INPUT PARAMETERS

WAVE # .700000+000 MICRONS  
 WAVE = .000000 MICRONS  
 RELHUM = .000000 PERCENT  
 DENS# = .100000-000 PARTICLES/CC  
 TEMP = .500000+000 DEG C  
 DELTA (CONVERGENCE CRITERION) = .100000-001  
 LOOPING OPTION IN EFFECT FOR 2 AEROSOL COMPONENTS

RELATIVE HUMIDITY FOR THIS RUN = .00 PERCENT. WAVELENGTH = .700 MICRONS  
 INDEX OF REFRACTION FOR PURE WATER IS: 1.330000 - .0000001

MASS DENSITY OF WATER AT 5.00 DEG C IS: 1.00 GM/CC  
 INDX= 1 M= 1.330000 K = -.0000001. MASS DENSITY = 1.000000 GROWTH FACTOR = .0000. CONC = 1.000000+000 GM/CC  
 FOR COMPONENT NO. 2 INTERVAL NO. 1 33 RADII WERE USED. CONTRIBUTION TO CTSUM = 2.668850+001  
 FOR COMPONENT NO. 2 INTERVAL NO. 2 17 RADII WERE USED. CONTRIBUTION TO CTSUM = 1.405387+002  
 FOR COMPONENT NO. 1: VPF = 6.17094-012 MASS CONCENTRATION = 6.17094-012 GM/CC. KEXT = 1.67229-003 PER KM

\*\*\*\*\* END OF AEROSOL COMPONENT CYCLE NUMBER 1 \*\*\*\*\*

INDX= 2 M= 1.430000 K = -.0000001. MASS DENSITY = 1.000000 GROWTH FACTOR = .0000. CONC = 1.000000+001 GM/CC  
 FOR COMPONENT NO. 2 INTERVAL NO. 1 33 RADII WERE USED. CONTRIBUTION TO CTSUM = 2.668850+001  
 FOR COMPONENT NO. 2 INTERVAL NO. 2 17 RADII WERE USED. CONTRIBUTION TO CTSUM = 1.428248+002  
 FOR COMPONENT NO. 2: VPF = 6.17094-012 MASS CONCENTRATION = 6.17094-012 GM/CC. KEXT = 1.69517-003 PER KM

\*\*\*\*\* END OF AEROSOL COMPONENT CYCLE NUMBER 2 \*\*\*\*\*

TOTAL MASS CONCENTRATION = 1.23419-011 GM/CC: TOTAL KEYS = 3.36746-003 PER KM

TOTAL NUMBER OF RADII USED WAS 100

ATTENUATION COEF. = 2.72356-004 SQ-METERS/MILLIGRAM OF DRY AEROSOL MATERIAL

\*\*\* WARNING \*\*\* OPTIMAL PF EXPANSION ORDER OF 42 EXCEEDS INPUT IT = 1. PF VALUES SHOULD BE USED CAUTIOUSLY

THIS IS A MIXED CASE • SUBSEQUENT REFRACTIVE INDEX PRINT-OUTS ARE NOT GENERALLY VALID

DISTRIBUTION TYPE	WAVELENGTH (MICRONS)	REFRACTIVE INDEX	EXTINCTION X SECTION (SQ MICRONS)	SCATTERING X SECTION (SQ MICRONS)	ALBDO
5	.7000	1.4300(1.00001)	1.68372949600220+002	1.68372949600220+002	1.000000000000000+000
K(EXT) = 3.3674590-003; K(SCA) = 3.3674590-003; K(RAD) = 4.9359845-003 ALL PER KM					

WAVENUMBER = 1.428571+004 CM-1 DENSITY = 2.000000-002 PARTICLES PER CC

SUMMARY OF RESULTS FOR THIS RUN ARE AS FOLLOWS :

WAVELENGTH (MICROMETERS)	REL. HUMIDITY (PERCENT)	AEROSOL MASS (GM/(SQ.CM-KM))	K(EXTINCTION) (PER KM)
.700000	.000000	1.23419-006	3.36746-003

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INTEGER CONTROL PARAMETERS: N WAVE MINDX IW IDSTP NRADI IT IANG NCRDS ITOT NUNIT MORTE IAPX  
 1 1 0 7 0 1 0 3 1 23 0 8

\*\*\* WATER ONLY CASE \*\*\*

AEROSOL PARAMETERS ARE RLO= .1000+000 RHI= .1500+002 CUE= .3000+002 A= .4000+001 VIS= .6000+001

NORMALIZATION FACTOR FOR SIZE DISTRIBUTION = .1128782+005  
 AVERAGE NUMERICAL DRY VOLUME IS 5.599874-002 CUBIC MICROMETERS

SIZE-INTERVALS USED ARE AS FOLLOWS

INTERVAL NO. 1 RMIN = .10000 RMAX = .11892  
 INTERVAL NO. 2 RMIN = .11892 RMAX = 15.00000  
 INPUT PARAMETERS  
 WAVE = .106000+002 MICRONS  
 DWAVE = .000000 MICRONS  
 RELHUM = .000000 PERCENT  
 DENSHT = .100000+003 PARTICLES/CC  
 TEMP = .250000+002 DEG C  
 DELTA (CONVERGENCE CRITERION) = .100000-001

RELATIVE HUMIDITY FOR TH  
 INDEX OF REFRACTION FOR PURE WATER IS: 1.178200 - .0756201

MASS DENSITY OF WATER AT 25.00 DEG C IS: 1.00 GM/CC  
 INDX= 1 M= 1.178200 K = - .0756201. MASS DENSITY = 1.000000 GROWTH FACTOR = .0000. CONC = .00000 GM/CC

FOR COMPONENT NO. 1 INTERVAL NO. 1 9 RADII WERE USED. CONTRIBUTION TO CTSUM = 1.600058-004

\*\*\* CONVERGENCE LEVEL NOT REACHED FOR INTERVAL NO. 2 \*\*\*

FOR COMPONENT NO. 1 INTERVAL NO. 2 257 RADII WERE USED. CONTRIBUTION TO CTSUM = 5.893135-003  
 FOR COMPONENT NO. 1 : VPF = 1.39527-009 MASS CONCENTRATION = 1.39527-009 GM/CC. KEXT = 1.50820-001 PER KM

TOTAL NUMBER OF RADII USED WAS 266

OMEGA SUB-1 = 5.6444562970592-001  
 OMEGA SUB-2 = 7.4147486686707-001

ATTENUATION COEF. = 1.08063-004 SQ-METERS/MILLIGRAM OF DRY AEROSOL MATERIAL  
 DISTRIBUTION WAVELENGTH REFRACTIVE INDEX SCATTERING X SECTION ALBDO  
 TYPE (MICRONS) (SQ MICRONS) (SQ MICRONS)  
 7 10.6000 1.178211 -.064211 6.05139648541808-003 1.45149653114863-003 2.398944646120



K(EXT) = 1.5081969-001: K(SCA) = 3.6180810-002: K(RAD) = 3.9616963-003 ALL PER KM

WAVENUMBER = 9.433962+002 CM-1

DENSITY = 2.492312+004 PARTICLES PER CC

GHG PHASE FUNCTION FOR ASYMETRY FACTOR (G) = .7843

COMPUTED PHASE FUNCTION AT ZERO DEGREES IS 5.2465

GHG PHASE FUNCTION AT ZERO DEGREES IS 3.7157

----- GHG VALUES -----			
MU	PHASE FUNCTION	MU	PHASE FUNCTION
.960289866	.2677733749+001	.796666488	.6179881915+000
-.183434647	.4108893569-002	-.525532417	.2865489456-002
		.525532417	.1655803137+000
		.2266309719-002	-.960289866
			.1998729800-002

TRUE OMEGA = .2399 INTEGRATED GHG PHASE FUNCTION = 3.0146 AND PERCENT ERROR = .0000

# GHG COEFFICIENTS

L	OMEGA	L	OMEGA	L	OMEGA
1	.239894+000	2	.598084+000	3	.723577+000
5	.569799+000	6	.447981+000	7	.306446+000
				4	.676869+000
				8	.153074+000

PERCENT ERRORS: OMEGA 0 = .000  
 OMEGA 1 = 5.960  
 OMEGA 2 = -2.414

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C C      PROGRAM AGAUSX
C C
C C REVISION DATE   25 MAY,    1980
C C
C C FOR OPERATIONAL QUESTIONS, OR POSSIBLE INACCURACIES,  
C C THAT YOU MAY HAVE OR FIND CONCERNING THIS PROGRAM,  
C C PLEASE CONTACT DR. R.C. SHIRKEY, ATMOSPHERIC SCIENCES LAB.,  
C C WSMR, N.M. #8002: PHONE (505) 678-4200 OR AUTOVON 278-4200.  
C C  
C C A MAJORITY OF THE WORK FOUND HEREIN WAS PERFORMED AT NEW  
C C MEXICO STATE UNIVERSITY, DEPT OF PHYSICS, BY DR. A. MILLER.  
C C THANKS ARE ALSO DUE TO DR. R.B. GOMEZ (ASL) AND  
C C DR. G.H. GOEDECKE (NMSU).  
C C  
C C PURPOSE:  
C C     TO CALCULATE EXTINCTION COEFFICIENTS, ETC., AND PRODUCE  
C C LEGENDRE EXPANSION COEFFICIENTS/ PHASE FUNCTIONS/ SCATTERING  
C C FRACTIONS UNDER A WIDE VARIETY OF CONDITIONS AND AEROSOL  
C C DISTRIBUTIONS AT ONE OR MORE WAVELENGTHS. THE PHASE FUNCTION  
C C IS NORMALIZED TO 4 PI OMEGA ZERO AND MAY BE RENORMALIZED BY  
C C DIVISION BY THE APPROPRIATE CONSTANT(S).  
C C ***** INPUT *****  
C C  
C C CARD I - INTEGER CONTROL PARAMETERS: NWAVE, NINDX, IW, IDSTP,  
C C          NRADI, IT, LANG, NCARDS, ITOT, NUNIT, MQRTG, IAPX  
C C          FORMAT (I2I5)  
C C NWAVE: IS THE NO. OF WAVELENGTHS, OR REL. HUMIDITY VALUES TO BE  
C C TREATED IN THIS RUN. SEE COMMENTS CIRCA READ OF WAVE, DWAVE, ETC.  
C C N-B. NWAVE MUST BE .LE. 5  
C C NINDEX: IS THE NBR OF AEROSOL COMPONENTS WHICH WILL HAVE DIFFERENT  
C C OPTICAL CONSTANTS, MASS DENSITIES OR MASS CONCENTRATIONS.  
C C IW = 0 WILL SET THE REFRACTIVE INDEX OF THE DRY AEROSOL EQUAL  
C C TO THAT OF WATER AT THE INPUT WAVELENGTH AND TEMP. IF IW.NE.O  
C C AND HANELS' GROWTH FACTOR=ZERO (EMUA=O -CARD 4), THEN THE  
C C INPUT REFRACTIVE INDEX (EMA,CAYA) WILL BE USED FOR THE AEROSOL.  
C C OTHERWISE THE REFRACTIVE INDEX IS ADJUSTED PER HANEL (SEE BELOW).  
C C IDSTP: IDENTIFIES TYPE OF AEROSOL SIZE DISTRIBUTION TO BE USED.  
C C NRADI: NO. OF PARTICLE RADII TO BE EXPECTED FOR IDSTEP=O OR 3;  
C C       THE INPUT VALUE OF NRADI IS IGNORED FOR IDSTEP NOT ZERO OR 3.  
C C       NRADI MUST BE LESS THAN 513.  
C C IT: IS THE NUMBER OF GAUSS-LEGENDRE ANGLES (ORDER OF EXPANSION)  
C C IF LANG=O OR NBR OF ANGLES BETWEEN O DEG AND 180 DEG IF LANG=.1.  
C C IF ONLY EXTINGTION COEFFICIENTS, ETC. ARE DESIRED, I.E. NOT PHASE  
C C FUNCTIONS, THEN SET -IT- EQUAL TO ONE.  
C C LANG=: O FOR COMPUTATIONS OF PHASE FN. AT -IT- GAUSS-LEGENDRE  
C C QUADRATURE ANGLES; NO SCATTERING FRACTIONS WILL BE PRINTED.  
C C LANG=#1 FOR COMPUTATIONS OF SCATTERING FRACTIONS AND PHASE  
C C FUNCTIONS AT -IT- EQUALLY SPACED ANGLES BETWEEN O AND 180 DEG.  
C C LANG=#2 WILL ALLOW -IT- USER SUPPLIED ANGLES TO BE READ -  
C C FORMAT (16F5.I). THIS REQUIRES AT LEAST ONE CARD OF TYPE IA.  
C C NCARDS: =1 WRITE/PUNCH LEGENDRE COEFFICIENTS AND ORDER OF EXPANSION  
C C           ON UNIT# - FORMAT (E25,I4,Ix,i5);  
C C           =2 WRITE/PUNCH SCATTERING FRACTIONS, PHASE FUNCTIONS, COSINES AND  
C C             COUNTER ON UNIT# - FORMAT (3(E12,F,X),I5);  
C C           =3 WRITE/PUNCH BOTH SCATTERING FRACTIONS, PHASE FUNCTIONS,
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C COSINES, COUNTER, AND LEGENDRE COEFFICIENTS AND ORDER OF EXPANSION AGXM0660  
 C ON NUNIT - FORMATS (3E12.6,IX,15) AND (E25.14,IX,15): AGXM0670  
 C SCATTERING FRACTIONS, PHASE FUNCTIONS, COSINES, AND COUNTER AGXM0680  
 C (RESPECTIVELY) ARE ALWAYS WRITTEN/PUNCHED BEFORE THE LEGENDRE AGXM0690  
 C COEFFICIENTS AND ORDER OF EXPANSION (RESPECTIVELY). AGXM0700  
 C ITOT: WORKS IN CONJUNCTION WITH NCRODS AND NWAVE TO WRITE/PUNCH AGXM0710  
 C EITHER INDIVIDUAL WAVELENGTH VALUES OR AVERAGED WAVELENGTH VALUES AGXM0720  
 C OR BOTH ON NUNIT: #1 FOR INDIVIDUAL WAVELENGTHS; #2 FOR AVERAGED AGXM0730  
 C WAVELENGTHS; #3 FOR BOTH. AGXM0740  
 C NUNIT: DEFINES DEVICE NUMBER..SEE PREVIOUS COMMENT CARD. AGXM0750  
 C NWRITE=12345 WILL CAUSE PRINTS OF MIE EFFICIENCY FACTORS AT AGXM0760  
 C EVERY VALUE OF PARTICLE RADIUS USED IN THE MIE CALCULATIONS; AGXM0770  
 C SET NWRITE = 0 IF SUCH PRINTS ARE NOT DESIRED. AGXM0780  
 C IAPX: IF .GT. ZERO THE GHG (ANALYTIC) PHASE FUNCTION WILL BE AGXM0790  
 C CONSTRUCTED AT IAPX GAUSS-LEGENDRE ANGLES (ORDER OF EXPANSION). AGXM0800  
 C CARD 1A - USER SUPPLIED SET OF -IT- ANGLES FORMAT (16F5.1) AGXM0810  
 C 16 VALUES PER CARD, MORE THAN 1 CARD MAY BE NEEDED. AGXM0820  
 C THIS CARD IS ONLY NEEDED WHEN IANG=2. AGXM0830  
 C AGXM0840  
 C AGXM0850  
 C CARD 2 - DISTRIBUTION PARAMETERS: ONLY ONE TYPE PER RUN. AGXM0860  
 C FORMAT (6E12.6) - READ IN AGXPT1 - ALL UNITS IN MICRONS AGXM0870  
 C TYPE 0. USER SUPPLIED - NRADI+1 CARDS AGXM0880  
 C RLO, DELLR  
 C FF(I), I = 1, NRADI  
 C TYPE 1. LOG-NORMAL AGXM0890  
 C RBAR, SIGMA, RLO, RHI  
 C TYPE 2. DOUBLE EXPONENTIAL AGXM0900  
 C RLO, RHI, CUE, A, B AGXM0910  
 C TYPE 3. DEIRMEINDJIAN MODEL C AGXM0920  
 C - NO INPUT - AGXM0930  
 C TYPE 4. POWER LAW (JUNGE) AGXM0940  
 C RLO, RHI, CUE, A AGXM0950  
 C TYPE 5. MODIFIED GAMMA AGXM0960  
 C RLO, RHI, RC, ALF, GAM AGXM0970  
 C TYPE 6. MODIFIED GAMMA FUG MODEL AGXM0980  
 C RLO, RHI, RC, ALF, GAM, ELWC AGXM0990  
 C TYPE 7. POWER LAW AGXM1000  
 C VIS AGXM1010  
 C TYPE 8. CONTINENTAL BIMODAL AGXM1020  
 C - NO INPUT - AGXM1030  
 C TYPE 9. MARITIME BIMODAL AGXM1040  
 C - NO INPUT - AGXM1050  
 C TYPE 10. URBAN BIMODAL AGXM1060  
 C - NO INPUT - AGXM1070  
 C TYPE 11. USER SUPPLIED BIMODAL AGXM1080  
 C FOA, RBARA, SGA, FOC, RBARC, SGL AGXM1090  
 C TYPE 12. MARSHALL-PALMER RAIN MODEL AGXM1100  
 C RAIN AGXM1110  
 C CARD 3 - CONTROL PARAMETERS: FORMAT (6E12.6) AGXM1120  
 C WAVE, DWAVE, RELHUM, DENSH, TEMP, DELTA AGXM1130  
 C FOR LOOPING OVER RELATIVE HUMIDITY ADD AGXM1140  
 C NWAVE-1 CARDS CONTAINING RELHUM,TEMP - FORMAT(2E12.6) AGXM1150  
 C SEE DWAVE BELOW. AGXM1160  
 C WAVE: IS WAVELENGTH IN MICROMETERS. AGXM1170  
 C DWAVE: IS THE WAVELENGTH INCREMENT IN MICROMETERS. IF DWAVE IS AGXM1180  
 C AGXM1190  
 C AGXM1200  
 C AGXM1210  
 C AGXM1220

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C LESS THAN 1.E-4, A SPECIAL CASE APPLIES USED FOR LOOPING OVER
C NWAVE VALUES OF RELHUM. THE FIRST TIME THIS CARD IS READ IT MUST
C CONTAIN: WAVE,DWAVE,RELHUM,DENSH,TEMP,AND DELTA; THE SECOND AND
C SUBSEQUENT TIMES IT MUST ONLY HAVE RELHUM AND TEMP ON IT.
C THIS REQUIRES REPEITION OF CARD 4.
C RELHUM: IS RELATIVE HUMIDITY IN PERCENT.
C DENSH: IS PARTICLE NUMBER PER CUBIC CENTIMETER.
C USER-SUPPLIED VALUE OF DENSH WILL BE IGNORED FOR IDSTP=3 OR GT 6
C BECAUSE THOSE DISTRIBUTIONS CARRY PRE-DETERMINED DENSITY VALUES.
C ALSO, IF DENSH IS LESS THAN 1E-4, THE PARTICLE NUMBER DENSITY
C WILL BE CALCULATED FROM MASS DENSITY AND MASS CONCENTRATION.
C TEMP: IS THE TEMPERATURE OF THE ATMOSPHERE IN DEGREES C.
C DELTA: IS THE CONVERGENCE CRITERION WITHIN A PARTICULAR SIZE
C RANGE INTERVAL: HALVING IS TERMINATED WHEN THE QUANTITY DEL
C IS LESS THAN DELTA.
C
C CARD 4 - OPTICAL AND PHYSICAL DATA (READ IN AGXPT2)
C FORMAT (4F10.5,E15.7)
C EMA, CAYA, EMUA, RHOA, CONC
C REPEAT (NWAVE*NINDX) TIMES: IF IDSTP=6 THIS CARD IS NOT NEEDED.
C EMA: IS THE REAL PART OF THE INDEX OF REFRACTION OF DRY AEROSOL.
C CAYA: IS THE IMAGINARY PART OF REFRACTIVE INDEX FOR DRY AEROSOL.
C ***** CAYA IS ASSUMED TO BE NEGATIVE *****
C ***** DO NOT ENTER CAYA WITH A NEGATIVE SIGN !!!!! *****
C EMUA: IS HANEL'S GROWTH FACTOR (MU-BAR)/ACCRETION COEF.
C RHOA: IS THE MASS DENSITY(1P, GRAV) OF DRY AEROSOL.
C CONC: IS THE MASS CONCENTRATION(GM/CC) OF DRY AEROSOL.
C
C ***** END INPUT *****
C
C REL. HUMIDITY TREATMENT PER G. HANEL/1976 ADV. IN GEOPHYS.
C USAGE REQUIRES AGAUSX,AGXPT1,AGXPT2,AGXPT3,GAUS,GUSET,ANGLE,
C MIEGX,WATER: FOR ANALYTIC PHASE FUNCTION CALCULATION
C INCLUDE GPHASX,GUSSTX,PRINTX.
C
C REAL KEXT,KSCAT,KBKT
C DIMENSION F(513),R(513),C(100),PSUM(100),PSUMT(100),RK(9),DR(8)
C DIMENSION PL(100,100),OL(100),RMS(100),PC(100),H(100),OUT(5,4)
C DIMENSION SCAT(100),SCATT(100),OLT(100)
C COMMON /BK2/PL,OL,RMS,PC,C,H,ALBDO,LLLL,NCRDS,IT,ITT,NRADI
C COMMON /BK3/F,R,PSUM,SCAT,RR,DR,WAVE,EM,CAY,EMH,PI,IDSTP,
C MQRTE,NKG,NHALV,NI
C PRINT OUT HEADING
C WRITE (6,100)
C ***** READ INTEGER CONTROL PARAMETERS FOR THIS RUN *****
C READ (5,103) NWAVE,NINDX,1W,IDSTP,NRADI,IT,IANG,NCRDS,ITOT,
C NUNIT,MQRTE,IAPX
C IF (IDSTP.GT.12) GO TO 1
C IF (IT.LE.1) IT=1
C IF (NWAVE.EQ.0) NWAVE=1
C IF (NUNIT.EQ.0) NUNIT=4
C IF (IAPX.GT.0) IT=1
C IF (IAPX.GT.0) IANG=0
C IF (IDSTP.EQ.12) 1W=1
C IF (NINDX.LT.1.OR.IDSTP.EQ.6.OR.IDSTP.EQ.12) NINDX=1
C WRITE (6,104) NWAVE,NINDX,1W,IDSTP,NRADI,IT,IANG,NCRDS,ITOT,
C NUNIT,MQRTE,IAPX
C
AGXM1230
AGXM1240
AGXM1250
AGXM1260
AGXM1270
AGXM1280
AGXM1290
AGXM1300
AGXM1310
AGXM1320
AGXM1330
AGXM1340
AGXM1350
AGXM1360
AGXM1370
AGXM1380
AGXM1390
AGXM1400
AGXM1410
AGXM1420
AGXM1430
AGXM1440
AGXM1450
AGXM1460
AGXM1470
AGXM1480
AGXM1490
AGXM1500
AGXM1510
AGXM1520
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AGXM1540
AGXM1550
AGXM1560
AGXM1570
AGXM1580
AGXM1590
AGXM1600
AGXM1610
AGXM1620
AGXM1630
AGXM1640
AGXM1650
AGXM1660
AGXM1670
AGXM1680
AGXM1690
AGXM1700
AGXM1710
AGXM1720
AGXM1730
AGXM1740
AGXM1750
AGXM1760
AGXM1770
AGXM1780
AGXM1790

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C
IF (I*EQ.0) WRITE (6,122)
INITIALIZE QUANTITIES USED IN SUMMATIONS
DO 2 I=1,IT
  OLT(I)=0.E0
  OL(I)=0.E0
  PSUM(I)=0.E0
  SCATT(I)=0.E0
2  PSUMT(I)=0.E0
  KEXTI=0.E0
  KSCAT=0.E0
  KBAKT=0.E0
  CATTN=0.E0
  ITT=IT-1
  PI=3.1415926535898E+00
  IF (IANG.EQ.1).OR.(IANG.EQ.2)) GO TO 3
  WHEN IANG=0, ROUTINE GUSFT IS CALLED TO SET-UP THE ABSCISSAE AND
  WEIGHTS USED FOR CALCULATING THE PHASE-FUNCTION AT -1/- POINTS
  USED FOR NUMERICAL INTEGRATION VIA GAUSS-LEGENDRE QUADRATURE AND
  TO GET THE PHASE FUNCTION EXPANSION COEFS, OLI).
  THE WEIGHTS ARE PLACED IN THE ARRAY H(), AND THE COSINES OF THE
  ANGLES ARE PLACED IN THE ARRAY C().
  CALL GUSFT(SCATT,F,PI)
  IF (ITT.LT.3) ITT=3
  GO TO 7
3  CALL ANGLE(PI,IANG)
  SUBROUTINE ANGLE IS CALLED WHEN IANG=1 OR 2 TO SET-UP THE ANGLES
  AT WHICH PHASE FUNCTIONS AND SCATTERING FRACTIONS WILL BE
  CALCULATED. ANGLES GO INTO ARRAY H() AND COSINES IN C().
7  CONTINUE
  DETERMINE DETAILS OF AEROSOL SIZE-DISTRIBUTION VIA AGXPTI
  CALL AGXPTI(DENS,FSUM,VOL,NRADII)
  IF (IDSTP.EQ.6.OR.IDSTP.EQ.12) ELWC=DENS
  DRYVOL IS THE AVERAGE VOLUME OF THE DRY AEROSOL PARTICLES IN
  CUBIC MICROMETERS.
  DRYVOL=VOL
  ** READ INPUT PARAMETERS **
  READ (5,105) WAVE,DWAVE,RELHUM,DENSH,TEMP,DELTA
  IF (NWAVE.EQ.1) DWAVE=0.E0
  WRITE (6,106) WAVE,DWAVE,RELHUM,DENSH,TEMP,DELTA
  IF (NINDX.GT.1) WRITE (6,107) NINDX
  IF ((DWAVE.LT.1E-04).AND.(NWAVE.GT.1)) WRITE (6,108) NWAVE
  IF ((DWAVE.GE.1E-04).AND.(NWAVE.GT.1)) WRITE (6,109) NWAVE
  IF (DENSH.LT.1E-05) WRITE (6,110)
  ENWAV=FLOAT(NWAVE)
  IF (DWAVE.LT.1.E-4) GO TO 8
  WAVE=WAWE-DWAVE
8  DO 9 NWV=1,NWAVE
  IF (DWAVE.GT.1.E-4) GO TO 10
  IF (NWV.EQ.1) GO TO 11
  READ (5,105) RELHUM,TEMP
  GO TO 11
10  WAVE=WAWE+DWAVE
11  VOL=DRYVOL
  DETERMINE WHETHER THE USER SUPPLIED PARTICLE NUMBER DENSITY DENSH
  SHOULD BE OVERIDDEN BECAUSE THE CHOSEN IDSTP CASE HAS FIXED
  PARAMETERS, AND/OR IF NUMBER DENSITIES ARE TO BE CALCULATED LATER
  FROM THE AVG PARTICLE VOLUME, MASS DENSITY, AND MASS CONCENTRATION
AGXM1800
AGXM1810
AGXM1820
AGXM1830
AGXM1840
AGXM1850
AGXM1860
AGXM1870
AGXM1880
AGXM1890
AGXM1900
AGXM1910
AGXM1920
AGXM1930
AGXM1940
AGXM1950
AGXM1960
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AGXM2020
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AGXM2110
AGXM2120
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AGXM2160
AGXM2170
AGXM2180
AGXM2190
AGXM2200
AGXM2210
AGXM2220
AGXM2230
AGXM2240
AGXM2250
AGXM2260
AGXM2270
AGXM2280
AGXM2290
AGXM2300
AGXM2310
AGXM2320
AGXM2330
AGXM2340
AGXM2350
AGXM2360

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      LLLL=0
      IF (IDSTP.EQ.6) GO TO 12
      IF (IDSTP.EQ.3.OR.IDSTP.GE.7) LLLL=1
      IF (LLLL.EQ.1) GO TO 12
      IF (DENS.H.E-4) GO TO 12
      LLLL=1
      DENS=DENSH
      12 CONTINUE
      C RESTRICT RELATIVE HUMIDITY TO MAX OF 99 PERCENT.
      IF (RELHUM.GE.99.E+00) RELHUM=99.0E+000
      WRITE (6,111) RELHUM,WAVE
      IF (DENS.EQ.0.0) DENS=1.0E+00
      GNU=1.0E+04/WAVE
      IF (IDSTP.EQ.6.OR.IDSTP.EQ.12) DENS=ELWC
      C DENS IS USED AS AN ALIAS TO PASS ELWC TO ROUTINE AGXPT2.
      CALL AGXPT2(RELHUM,CTSUM,CSSUM,CRSUM,VOL,THASS,DENS,QATTN,TEMP,
      1 DELTA,NINDX,IAPX,IW)
      IF (IANG.NE.0) GO TO 13
      AMAX=2.E+0*PI*EMM*(RNRAD1)/WAVE
      LMAX=3*FIX(AMAX)
      IF ((LMAX.GT.1).AND.(IAPX.EQ.0)) WRITE (6,112) LMAX,IT
      13 CALL AGXPT3(CTSUM,CSSUM,CHSUM,GNU,DENS,NINDX,NUNIT,IANG,ITOT,IAPX)
      C SUM QUANTITIES OVER INDEX NWV.
      DO 14 IK=1,IT
      OUT(IK)=OLT(IK)+OL(IK)
      SCATT(IK)=SCAT(IK)+SCATT(IK)
      14 PSUM(IK)=PSUM(IK)+PSUM(IK)
      C KEXT BECOMES THE TOTAL EXTINCTION COEF. (PER KILOMETER)
      C KSCAT BECOMES THE TOTAL SCATTERING COEF. (PER KM)
      C KBAKT BECOMES THE TOTAL RACK-SCATTERING(RADAR) COEF (PER KM)
      C ARRAY OUT(,) HOLDS SOME QUANTITIES FOR LATER PRINTOUTS
      KEXT=KEXT+CTSUM
      KSCAT=KSCAT+CSSUM
      KBAKT=KBAKT+CRSUM
      CATTN=CATTN+QATTN
      OUT(NWV,1)=WAVE
      OUT(NWV,2)=RELHUM
      OUT(NWV,3)=1/MASS*1.E5
      OUT(NWV,4)=CTSUM
      C GPHASX WILL CONSTRUCT THE GHG ANALYTIC PHASE FUNCTION AT
      C IAPX ANGLES.
      IF (IAPX.GT.0) CALL GPHASX(PSUM,PL,OL,RMS,PC,H,SCAT,SCATT,OLT,PI,
      +NUNIT,IAPX,NCRDS)
      IF ((NWAVE.GT.1).AND.(DWAVE.GE.1.E-04)) WRITE (6,113) NWV
      IF ((NWAVE.GT.1).AND.(DWAVE.LT.1.E-04)) WRITE (6,114) NWV
      9 CONTINUE
      C END OF NWAVE LOOP
      IF (IAPX.GT.0) GO TO 20
      IF (NWAVE.EQ.1) GO TO 15
      C DIVIDE BY NBR OF VALUES OF NWV TO GET AVERAGED RESULTS.
      DO 16 I=1,IT
      OL(I)=OLT(I)/ENWAV
      SCATT(I)=SCATT(I)/ENWAV
      PSUM(I)=PSUM(I)/ENWAV
      IF (((NCRDS.EQ.2).OR.(INCRDS.EQ.3)).AND.((ITOT.EQ.2).OR.(ITOT.EQ.3
      + ))) WRITE (NUNIT,115) SCATT(I),PSUM(I),C(I),1
      16 CONTINUE

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IF (IANG.NE.0) GO TO 21
DO 17 I=1,17
  I1=I-1
  IF (((NCRDS.EQ.1).OR.(NCRDS.EQ.3)).AND.((ITOT.EQ.2).OR.(ITOT.EQ.3
    + ))) WRITE (NUNIT,116) OL(I),I1
17 CONTINUE
21 KEXTT=KEXTT/ENWAV
  KSCAT=KSCAT/ENWAV
  KBAKT=KBAKT/ENWAV
  CATTN=CATTN/ENWAV
15 WRITE (6,117)
  WRITE (6,118)
  DO 18 J=1,NWAVE
18 WRITE (6,119) (OUT(J,J),JJ=1,4)
  IF (NWAVE.NE.1) CALL AGXPRT(SCATT,KEXTT,KSCAT,KBAKT,CATTN,IANG,
    + ITOT,NUNIT)
20 CONTINUE
  GO TO 19
19 WRITE (6,120) IDSTP
19 STOP
20 FORMAT (1H,40X,3U(1H*))//,1X,40X,3H***,24X,3H***//,1X,
  +,40X,30H*** PROGRAM AGAUSX- ***//,1X,40X,3H***,24X,3H***//
  +,1X,40X,3U(1H*)//)
23 FORMAT (12I5)
24 FORMAT(11H,90HINTEGER CONTROL PARAMETERS: NWAVE NINDX 1W IDSTP NRAAGM3170
  +,1X,4X,9HNDWAVE = ,E12.6,8H MICRONS/,1X,6X,9HRELHUM = ,E12.6,
  +3X,13.2X,12.3X,11.4X,11.5X,11.3X,12.3X,15.2X,12)
25 FORMAT (6E12.6)
26 FORMAT(1H0,16HINPUT PARAMETERS/,1X,6X,9HWAVE = ,E12.6,8H MICRONSAGM3210
  +,1X,6X,9HNDWAVE = ,E12.6,8H MICRONS/,1X,6X,9HRELHUM = ,E12.6,
  +8H PERCENT/,1X,6X,9HDENSH = ,E12.6,8H PARTICLES/CC/,1X,6X,
  +9HTEMP = ,E12.6,6H DEG C/,1X,6X,19HDELTA (CONVERGENCE ,
  +13HCRITERION) = ,E12.6)
27 FORMAT (1H0,29HLOOPING OPTION IN EFFECT FOR ,12,
  +19H AEROSOL COMPONENTS)
28 FORMAT (1H0,39HRELATIVE HUMIDITY OPTION IN EFFECT FOR ,12,
  +7H VALUES)
29 FORMAT (1H0,40HWAVELENGTH LOOPING OPTION IN EFFECT FOR ,12,
  +12H WAVELENGTHS)
30 FORMAT(1H0,52H*** PARTICLE NUMBER DENSITY WILL BE CALCULATED FROMAGM3320
  +,41H MASS DENSITY AND MASS CONCENTRATION ***)
31 FORMAT (1H1,/,1X,33HRELATIVE HUMIDITY FOR THIS RUN = ,F6.2,
  +25H PERCENT. WAVELENGTH = ,F10.3,8H MICRONS)
32 FORMAT (/49H *** WARNING *** OPTIMAL PF EXPANSION ORDER OF ,13, AGM3360
  + 22H EXCEEDS INPUT IT = ,13.24H. PF VALUES SHOULD BE , AGM3370
  + 15HUSED CAUTIOUSLY//)
33 FORMAT (1H0,/,1X,40(1H*),3X,31HEND OF WAVELENGTH CYCLE NUMBER ,13,AGM3390
  +3X,40(1H*))
34 FORMAT (1H0,/,1X,40(1H*),3X,38HEND OF RELATIVE HUMIDITY CYCLE NUMBAGM3410
  +,13,3X,40(1H*))
35 FORMAT (3(E12.6,1X),15)
36 FORMAT (E25.14,1X,15)
37 FORMAT(1H1,49H SUMMARY OF RESULTS FOR THIS RUN ARE AS FOLLOWS ://)AGM3450
38 FORMAT(1H,4X,48HWAVELENGTH REL.HUMIDITY AEROSOL MASS K(,AGM3460
  + 11HEXTINCTION),/1X,29H (MICROMETERS) (PERCENT)
  + ,6H (GM,25H/(50.CM-KM) (PER KM)//)
39 FORMAT (2F15.6,1P3E16.5)

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)20 FORMAT (//13H *** IDSTP = ,15,35H IS ILLEGAL. EXECUTION TERMINATEDAGXM3500
+
2H* //)
)22 FORMAT (//,1X,23H*** WATER ONLY CASE ***/)
END
AGXM3510
AGXM3520
AGXM3530

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SUBROUTINE ACXPT1(DENS,FSUM,VOL,NRADI)
  DIMENSION F(513),R(513),PSUM(100),DR(8),RR(9),FF(514),SCAT(100)
  COMMON /BK3/F,R,PSUM,SCAT,RR,DR,WAVE,EM,CAY,EMM,PI,IDSIP,
1  HQRTE,INKG,MHALV,NI
  WRITE (6,2)
  C  CHOOSE AND SET UP PARTICLE SIZE DISTRIBUTION
  IF (IDSIP.NE.0) GO TO (12,15,16,17,19,17,20,21,22,24,26),IDSIP
  C** TYPE 0: ARBITRARY USER-SUPPLIED DISTRIBUTION. THE NRADI VALUES
  C OF FF(J) MUST BE GIVEN, ONE PER CARD, ON EQUAL INCREMENTS DELLR
  C OF RADIUS AND READ IN ORDER, FROM SMALLEST RADIUS, RLO TO THE
  C LARGEST: NRADI MUST BE LESS THAN OR EQUAL TO 513.
  WRITE (6,7)
  READ (5,1) RLO,DELLR
  DO 9 J=1,NRADI
  R(J)=RLO+DELLR*FLOAT(J-1)
  9 READ (5,1) FF(J)
  DO 10 J=1,NRADI,5
  JK=J+4
  IF (JK.GT.NRADI) JK=NRADI
  10 WRITE (6,11) (R(K),FF(K),K=J,JK)
  WRITE (6,11)
  FF(NRADI+1)=FF(NRADI)
  RR(1)=RLO
  RR(2)=RLO+DELLR*FLOAT(NRADI-1)
  MIN=0
  GO TO 28
  C** TYPE 1: LOG-NORMAL DISTRIBUTION
  12 READ (5,1) RBAR,SIGMA,RLO,RHI
  C SIGMA IS STANDARD DEVIATION, NOT LN(SIGMA)
  SIGMA=SIGMA
  SIGMA=ALOG(SIGMA)
  A=ABS(1.E0/(2.5066283E0*SIGMA))
  IF ((RHI-RLO).LE.1.E-4) GO TO 13
  RR(1)=RLO
  RR(3)=RHI
  GO TO 14
  13 RR(1)=RBAR*EXP(-4.E0*SIGMA)
  RR(3)=RBAR*EXP(4.E0*SIGMA)
  14 RR(2)=RBAR
  MIN=1
  WRITE (6,3) RBAR,SIGIN,RLO,RHI
  AVOL=4.18879E0*(RBAR**3.E0)*EXP(4.5E0*SIGMA*SIGMA)
  C HERE AND ELSEWHERE, AVOL IS THE VOLUME OBTAINED VIA
  C ANALYTICAL INTEGRATION OVER THE LIMITS RLO TO RHI =
  C INFINITY: THAT CAN ONLY BE DONE FOR A FEW IDSIP CASES.
  GO TO 28
  C** TYPE 2: DOUBLE EXPONENTIAL F(R)=CUE*A*EXP(-A*R)+(1-CUE)*B*EXP(-B*R).
  C RESTRICTIONS: RHI.GT.RLO, B.GT.A*GE.0, 0.LE.CUE.LE.1.0.
  15 READ (5,1) RLO,RHI,CUE,A,B
  WRITE (6,4) RLO,RHI,CUE,A,B
  RR(1)=RLO
  RR(3)=RHI
  RR(2)=0.5E0*(RLO+RHI)
  MIN=1
  GO TO 28
  C** TYPE 3: DEIRMENDUJIAN MODEL C.F(R) = 1.0, RLO.LE.R.LE.4*DELRD,

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C      FIR)=(4*DELDRD/R)**4, R*GE*(4*DELDRD)
C      NRADI IS READ IN EARLIER IN THE MAIN PROGRAM.
16     DENS=1.378E+04
      DELRD=0.02E0
      RLO=0.02E0
      RHI=RLO+DELDRD*FLOAT(NRADI-1)
      RR(1)=RLO
      RR(3)=RHI
      MIN=1
      RR(2)=RLO+4.E0*DELDRD
      GO TO 28
C**    TYPE 4 AND TYPE 7: POWER LAW. FIR = CUE*R**A
C      RLO*LE*R*LE.RHI; VIS=VISIBILITY IN KILOMETERS.
17     IF (IDSTP.EQ.4) GO TO 18
C**    TYPE 7 PRESCRIBED PARAMETER.
      READ (5,1) VIS
      RLO=0.1E0
      RHI=15.E0
      CUE=30.E0
      A=4.E0
      DENS=11.E0*(5.E0-ALOG10(VIS))
C**    TYPE 4 PRESCRIBED PARAMETERS.
18     IF (IDSTP.EQ.4) READ (5,1) RLO,RHI,CUE,A
      WRITE (6,5) RLO,RHI,CUE,A,VIS
      RR(1)=RLO
      RR(3)=RHI
      RR(2)=(0.5E0*(RLO*(-A)+RHI*(-A)))*(-1.E0/A)
      MIN=1
      GO TO 28
C**    TYPE 5: MODIFIED GAMMA/GENERALIZED KHIRGIAN-HAZIN
C      FIR) = (R*ALF)*EXP(-ALF*(R/RC)**GAM)/GAM)
C      RLO*LE*R*LE.RHI.
C**    TYPE 6: SPECIAL CASE FOR WATER FOGS OR CLOUDS,
C      IN WHICH CASE ELWC IS LIQUID WATER CONTENT
C      IN GRAMS PER CUBIC CENTIMETER:
C      ELWC IS IGNORED IF IDSTP = 5.
19     READ (5,1) RLO,RHI,RC,ALF,GAM,ELWC
      IF (IDSTP.EQ.6) DENS=ELWC
      WRITE (6,6) RLO,RHI,RC,ALF,GAM
      RR(1)=RLO
      RR(2)=RC
      RR(3)=RHI
      MIN=1
      B=ALF/(GAM*RC**GAM)
      AVOL=4.1888*B*(-3./GAM)*GAMMA((ALF+4.)/GAM)/GAMMA((ALF+1.)/GAM)
      GO TO 28
C**    TYPES 8,9,10: BIMODAL LOG-NORMAL DISTRIBUTIONS.
C      METHOD BELOW VALID FOR RRARC*EXP(-SGA).GT.RBARA*EXP(SGA)
C**    TYPE 8: CONTINENTAL BIMODAL.
20     FOA=4.E03
      FOC=2.1E0
      SGA=0.74E0
      SGC=0.81E0
      RBARA=0.03E0
      RBARC=0.4E0
      GO TO 23
C**    TYPE 9: MARITIME BIMODAL.

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PT100660
PT100670
PT100680
PT100690
PT100700
PT100710
PT100720
PT100730
PT100740
PT100750
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PT100790
PT100800
PT100810
PT100820
PT100830
PT100840
PT100850
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PT100910
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PT100960
PT100970
PT100980
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PT101000
PT101010
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PT101030
PT101040
PT101050
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PT101070
PT101080
PT101090
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PT101110
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PT101130
PT101140
PT101150
PT101160
PT101170
PT101180
PT101190
PT101200
PT101210
PT101220

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21 F0A=4.E02
   FOC=3.8E0
   SGA=0.68E0
   SGC=0.74E0
   RBARA=0.05E0
   RBARC=0.65E0
   GO TO 23
C** TYPE 10: URBAN BIMODAL.
22 F0A=2.E04
   FOC=0.6E0
   SGA=0.63E0
   SGC=.77E0
   RBARA=0.04E0
   RBARC=0.63E0
C CALCULATE RADII FOR TYPES 8,9,10.
23 RR(1)=RBARA*EXP(-4.E0*ABS(SGA))
   RR(2)=RBARA
   RR(3)=RBARA*EXP(4.E0*ABS(SGA))
   RR(4)=RBARC*EXP(-4.E0*ABS(SGC))
   RR(5)=RBARC*EXP(4.E0*ABS(SGC))
   MIN=2
   DO 60 J=1,4
   DO 60 I=1,4
   IF (RR(I+1).GT.RR(I)) GO TO 60
   HH=RR(I)
   RR(I)=RR(I+1)
   RR(I+1)=HH
60 CONTINUE
   GO TO 28
C** TYPE 11:
C USER SUPPLIED BIMODAL CASE: F0A AND FOC ARE THE NUMBER DENSITIES
C FOR THE ACCUMULATION (SMALLER RBAR) AND COARSE MODES,
C RESPECTIVELY, IN PARTICLES PER CUBIC CENTIMETER.
C SGA IS STD.DEVIATION FOR MODE A ** NOT LN(SIGMA) ***
C SGC IS STD.DEVIATION FOR MODE C ** NOT LN(SIGMA) ***
C ** NOTE, HOWEVER, THAT SGA AND SGC ARE THE LOGS OF THE
C STANDARD DEVIATIONS IN THE PRE-CODED CASES TYPE 8-10.
24 READ (5,1) F0A,FOC,RBARA,RBARC,SGA,SGC
   WRITE (6,25) F0A,RBARA,SGA,FOC,RBARC,SGC
   SGA=ABS(ALOG(SGA))
   SGC=ABS(ALOG(SGC))
   GO TO 23
C** TYPE 12: MARSHALL-PALMER RAIN MODEL.
C C.F. MASON, PHYSICS OF CLOUDS, CH. ON RADAR METEOROLOGY.
C INPUT PARAMETER RAIN IS RAIN RATE IN MILLIMETERS/HOUR:
C ** EMA,CAYA, AND MHOA ARE REQUIRED FOR THIS DISTRIBUTION.
26 READ (5,1) RAIN
   ENZERO=9.08E0
   CAPL=41.E0*RAIN**(-0.21E0)
   DENS=ENZERO/CAPL
   AVOL=PI*(CAPL**(-3.E0))*1.E12
C CONVERT UNITS FROM CM-4 TO (CM-3)*(MICROMETERS**(-1)):
C THE FACTOR OF 2 CONVERTS THE M-P FORMULA FROM DIAMETER-TO
C RADIUS BASED FORM.
   ENZERO=2.E-4*ENZERO
   CAPL=2.E-4*CAPL
   MIN=0

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PT101230  
 PT101240  
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 PT101740  
 PT101750  
 PT101760  
 PT101770  
 PT101780  
 PT101790

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PT101800
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PT101910
PT101920
PT101930
PT101940
PT101950
PT101960
PT101970
PT101980
PT101990
PT102000
PT102010
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PT102340
PT102350
PT102360

RR(1)=1.E-4
RR(2)=2500.E0
WRITE (6,27) RAIN,DENS
C THE NEXT BLOCK IS COMMON TO ALL DISTRIBUTIONS.
C IT SETS THE NMAX VALUES OF RADIUS, R(KK).
28 MAX=9
NHALV=MAX-MIN
NMAX=1+2*MAX
NI=2*MIN
NLAST=NI+1
NKG=2*NHALV
ENKG=FLOAT(NKG)
DO 29 I=1,NI
DR(I)=RR(I+1)-RR(I)
DO 29 K=1,NKG
KK=(I-1)*NKG+K
29 R(KK)=RR(I)+(FLOAT(K-1))*DR(I)/ENKG
RINMAX)=RR(NLAST)
C BRANCH AGAIN CALCULATE THE DIFFERENT F(R) ON THE NMAX POINTS R(K)
IF (IDSTP.NE.0) GO TO (31,33,35,38,41,39,43,43,43,46),IDSTP
C** TYPE 0: ARBITRARY
DELR=(RR(2)-RLO)/ENKG
DO 30 KK=1,NMAX
JKK=1+(FLOAT(KK-1))*DELR/DELLR
RRJJK=RR(1)+DELLR*FLOAT(JKK-1)
30 F(KK)=FF(JKK)+(R(KK)-RRJJK)*(FF(JKK+1)-FF(JKK))/DELLR
GO TO 48
C** TYPE 1: LOG NORMAL
31 DEN=2.E0*SIGMA*SIGMA
DO 32 KK=1,NMAX
GNUM=ALOG(R(KK)/RBAR)
32 F(KK)=EXP(-GNUM*GNUM/DEN)*A/R(KK)
GO TO 48
C** TYPE 2: DOUBLE EXPONENTIAL
33 DO 34 KK=1,NMAX
FKK=(1.E0-CUE)*B*EXP(-B*R(KK))
34 F(KK)=FKK+CUE*A*EXP(-A*R(KK))
GO TO 48
C** TYPE 3: DEIRHENDJIAN MODEL C.
35 DO 36 KK=1,NMAX
36 F(KK)=1.E0
NKG1=NKG+1
DO 37 KK=NKG1,NMAX
37 F(KK)=(RR(2)/R(KK))**4.E0
GO TO 48
C** TYPES 4 AND 7: POWER LAW
38 GO TO 39
39 DO 40 KK=1,NMAX
40 F(KK)=CUE*R(KK)**(-A)
GO TO 48
C** TYPE 5 AND TYPE 6: MODIFIED GAMMA
41 DO 42 KK=1,NMAX
42 F(KK)=(EXP(-B*R(KK))*GAMMA)*R(KK)**ALF
GO TO 48
C** TYPES 8,9,10,11: BIMODAL LOG-NORMAL DISTRIBUTIONS
43 DENA=2.E0*SGA*SGA
DENC=2.E0*SGC*SGC

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PT102370
PT102380
PT102390
PT102400
PT102410
PT102420
PT102430
PT102440
PT102450
PT102460
PT102470
PT102480
PT102490
PT102500
PT102510
PT102520
PT102530
PT102540
PT102550
PT102560
PT102570
PT102580
PT102590
PT102600
PT102610
PT102620
PT102630
PT102640
PT102650
PT102660
PT102670
PT102680
PT102690
PT102700
PT102710
PT102720
PT102730
PT102740
PT102750
PT102760
PT102770
PT102780
PT102790
PT102800
PT102810
PT102820
PT102830
PT102840
PT102850
PT102860
PT102870
PT102880
PT102890
PT102900
PT102910
PT102920
PT102930

FAA=FOA/SGA
FCC=FOC/SGC
DO 44 KK=1,NMAX
  GNUMA=ALOG(R(KK)/RBARA)
  GNUMC=ALOG(R(KK)/RBARC)
  FA=FAA*EXP(-GNUMA*GNUMA/DENA)
  FC=FCC*EXP(-GNUMC*GNUMC/DENC)
  44 F(KK)=(FA+FC)/R(KK)
  DENS=FOA+FOC
  WRITE (6,45) DENS
  VOLA=4.18879E0*(RBARA**3.E0)*EXP(4.5E0*SGA*SGA)*FOA
  VOLC=4.18879E0*(RBARC**3.E0)*EXP(4.5E0*SGC*SGC)*FOC
  AVOL=(VOLA+VOLC)/DENS
GO TO 48

C** TYPE 12: MARSHALL-PALMER MAIN MODEL
46 DO 47 KK=1,NMAX
47 F(KK)=ENZERO*EXP(-CAPL*R(KK))
C CALCULATE NORMALIZED F(KK) AND SOME DRY VOLUMES USING ALL NMAX
C VALUES OF RADII.
C (VOL=AVERAGE PARTICLE VOLUME IN A DISTRIBUTION). THE
C NORMALIZATION AND FURTHER VOLUMES ARE RECALCULATED LATER
C BY THE HALVING INTEGRATION METHOD.
48 FSUM=0.E0
  IF(F(1).LT.0.E0)F(1)=0.E0
  DO 49 J=2,NMAX
  IF(F(J).LT.0.E0)F(J)=0.E0
  49 FSUM=FSUM+0.5E0*(F(J)+F(J-1))*(R(J)-R(J-1))
  DO 50 J=1,NMAX
  50 F(J)=F(J)/FSUM
  WRITE (6,8) FSUM
  NRADI =NMAX
  IF (IDSTP.EQ.1.0R.IDSTP.EQ.5.0R.IDSTP.GE.8) WRITE (6,51) AVOL
  VOL=0.E0
  DO 52 J=2,NMAX
  52 VOL=VOL+2.0944E0*(F(J)*R(J)**3.E0+F(J-1)*R(J-1)**3.E0)*(R(J)-R(J-1))
  1
  WRITE (6,53) VOL
C THE VOLUME PER PARTICLE CALCULATED HERE IS OBTAINED USING
C ALL AVAILABLE (NMAX VALUES) VALUES FOR THE PARTICLE RADII.
  WRITE (6,54)
  DO 56 INT=1,NI
  INF=INT+1
  56 WRITE (6,55) INT,RR(INT),RR(INF)
  RETURN
  1 FORMAT (6E12.6,I3)
  2 FORMAT (1H, //24H AEROSOL PARAMETERS ARE )
  3 FORMAT (1H+,24X,6HGBAR= ,E12.6,5X,7HSIGMA= ,E12.6,7H KLO = ,E12.6,
    + 7H RHI = ,E12.6/)
  4 FORMAT (1H+,24X,5HRL0= ,E10.4,1X,5HRL1= ,E10.4,1X,5HCUE= ,E10.4,
    + 1X,3HA= ,E10.4,1X,3HB= ,E10.4/)
  5 FORMAT (1H+,24X,5HRL0= ,E10.4,1X,5HRL1= ,E10.4,1X,5HCUE= ,E10.4,
    + 1X,3HA= ,E10.4,1X,4HVIS= ,E10.4/)
  6 FORMAT (1H+,24X,5HRL0= ,E10.4,1X,5HRL1= ,E10.4,1X,5HRC= ,E10.4,1X,
    + 5HALF= ,E10.4,1X,5HGAM= ,E10.4/)
  7 FORMAT (1H, 5(26H RADIUS RELATIVE NO. ))
  8 FORMAT (1H, 5(26H NORMALIZATION FACTOR FOR SIZE DISTRIBUTION = ,E14.7)
  11 FORMAT (1X,10(E12.6,1X))

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25 FORMAT (/1X,7HN(A) = ,E12.6,2X,9H RBARA = ,E12.6,2X,12H SIGMA(A) =PT102940
+
+ ,E12.6,/,1X,7HN(C) = ,E12.6,2X,9H RBARC = ,E12.6,2X, PT102950
+ 12H SIGMA(C) = ,F12.6/) PT102960
27 FORMAT (/1X,42H MARSHALL-PALMER RAIN MODEL : RAIN RATE = ,1PE10.3,PT102970
+ 21H MM PER HOUR, DENS = ,1PE12.6,8H PART/CC) PT102980
45 FORMAT (/ ,1H ,50H** BIMOVAL DISTRIBUTION**EQUIVALENT DENSITY ISPT102990
+ ,1PE13.6,18H PARTICLES PER CC,/) PT103000
51 FORMAT(/45H AVERAGE ANALYTIC DRY VOLUME PER PARTICLE IS ,3X, PT103010
+ 1PE12.6,18H CUBIC MICROMETERS) PT103020
53 FORMAT (1X,47H AVERAGE NUMERICAL DRY VOLUME IS PT103030
+ 1PE12.6,18H CUBIC MICROMETERS/) PT103040
54 FORMAT (1X,10X,35H SIZE-INTERVALS USED ARE AS FOLLOWS/) PT103050
55 FORMAT (1H ,14H INTERVAL NO. ,13,5X,7HRMIN = ,F11.5,5X,8H RMAX = PT103060
+ ,F11.5) PT103070
END PT103080

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SUBROUTINE AGXPT2(RELHUM,CTSUM,CSSUM,CRSUM,TVOL,TMASS,DENS,CATTN, PT2X0100
1  TEMP,DELTA,NINUX,IAPX,IW) PT2X0110
DOUBLE PRECISION EMD,CAYD,ALPHAD,QTD,QSD,QRD,QD,01STRD,02STRD,DBLE PT2X0120
REAL KEXT,KEXTT,KEXOLD PT2X0130
DIMENSION F(513),R(513),DK(8),RR(9),C(100),P(100),PSUM(100) PT2X0140
DIMENSION PL(100,100),OL(100),RMS(100),PC(100),H(100),PSUMT(100) PT2X0150
DIMENSION PHH(100),PGG(100),PHHT(100),SCAT(100) PT2X0160
EQUIVALENCE (PHHT(1),PC(1)),(PGG(1),RMS(1)),(PHHT(1),OL(1)) PT2X0170
COMMON /BK2/PL,OL,RMS,PC,C,H,ALBDO,LLLL,NCROSS,IT,ITT,NRADI PT2X0180
COMMON /BK3/F,R,PSUM,SCAT,RR,DR,WAVE,EM,CAY,EMM,PI,IDSTP, PT2X0190
MQRTE,NKG,MHALV,NI PT2X0200
2  IN THIS SUBROUTINE THE FOLLOWING CONVENTIONS ARE USED IN PT2X0210
C PREFIXING VARIABLE NAMES: PT2X0220
C THE LETTER C IS USED FOR CROSS-SECTIONS PT2X0230
C THE LETTER Q IS USED FOR EFFICIENCY FACTORS PT2X0240
C THE LETTER K IS USED FOR EXTINCTION COEF. PER UNIT PATH (KM) PT2X0250
C THE LETTER T IS A SUFFIX FOR TOTAL VALUES PT2X0260
C THE LETTER O IS A PREFIX FOR OMEGA SUB 1 AND 2 CALCULATIONS PT2X0270
C FOR THE IDSTP=6 AND 12 CASES, DENS IS USED TO TRANSFER THE PT2X0280
LIQUID WATER CONTENT FROM THE MAIN PROGRAM TO THIS SUBROUTINE: PT2X0290
ELWC IS USED AS THE AEROSOL CONCENTRATION FOR THOSE CASES. PT2X0300
IF (IDSTP.EQ.6.OR.IDSTP.EQ.12) ELWC=DENS PT2X0310
OLSTAR=0.0EQ PT2X0320
OM2=0.0EQ PT2X0330
CTSUMT=0.0E+00 PT2X0340
CSSUMT=0.0E+00 PT2X0350
DENSNT=0.0EQ PT2X0360
CRSUMT=0.0E+00 PT2X0370
EMM=1.0EQ PT2X0380
NLINES=0 PT2X0390
BH=1.056E-3 PT2X0400
FACTORS BH AND CH ARE USED IN SIZE ADJUSTMENTS PT2X0410
FH IS THE SATURATION RATIO PT2X0420
FH=RELHUM/100.0EQ PT2X0430
CH=PH/(1.0EQ-FH) PT2X0440
CONCT=0.0EQ PT2X0450
KEXTT=0.0EQ PT2X0460
3  CONVERT VOL PER PARTICLE RECEIVED FROM MAIN PROGRAM VIA VARIABLE PT2X0470
TVOL TO DRY VOLUME PER PARTICLE IN CUBIC CENTIMETERS PT2X0480
DRYVOL=TVOL*1.0E-12 PT2X0490
TVOL=0.0EQ PT2X0500
TMASS=0.0EQ PT2X0510
DO 6 J=1,IT PT2X0520
PSUMT(J)=0.0EQ PT2X0530
PHH(J)=0.0EQ PT2X0540
PGG(J)=0.0EQ PT2X0550
6  PSUM(J)=0.0E+00 PT2X0560
CONVERT TEMP. TO KELVIN FOR SUBROUTINE WATER USAGE PT2X0570
TEMK=TEMP+273.16EU PT2X0580
SKIP SUBROUTINE WATER FOR THE IDSTP = 12 CASE, AND READ THE PT2X0590
OPTICAL DATA FOR RAIN AS EMUA,CAYA,ETC...NEEDED BECAUSE CASE PT2X0600
IDSTP=12 MAY BE AT WAVELENGTHS LONGER THAN FOUND IN ROUTINE PT2X0610
WATER. PT2X0620
IF (IDSTP.EQ.12) GO TO 8 PT2X0630
CALL WATER(WAVE,EMW,CAYW,TEMK,RHOW) PT2X0640
SUBROUTINE WATER RETURNS INTERPOLATED VALUES FOR EMW, CAYW AND PT2X0650

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C      RHOA AT WAVELENGTH = WAVE AND AT TEMPERATURE = TEMK (DEG K).
C      EMW IS REAL PART OF INDEX OF REFR FOR PURE WATER AT TEMP(DEG C).
C      CAYW IS IMAG. PART OF INDEX OF REFR. FOR PURE WATER:
C      CAYW, HERE IS POSITIVE, BUT TREATED AS NEGATIVE IN MIE-ROUTINE.
C      RHOA IS MASS DENSITY(1GM/CC) AT TEMPERATURE = TEMP (DEG C).
C      WRITE (6,9) EMW,CAYW,TEMP,RHOW
C      BEGIN LOOP OVER AEROSOL COMPONENTS INDEXED BY NK
C      DO 32 NK=1,NINDX
C      BYPASS READ OF EMA,CAYA,EIC. FOR IDSTP=6 CASE..USE WATER DATA
C      IF (IDSTP.NE.6) GO TO 10
C      EMA=EMW
C      CAYA=CAYW
C      RHOA=RHOW
C      CONC=ELWC
C      EMUA=0.0EQ
C      GO TO 11
C      *** READ OPTICAL AND PHYSICAL DATA ***
C      10 READ (5,2) EMA,CAYA,EMUA,RHOA,CONC
C      IF (IW.EQ.0) EMA=EMW
C      IF (IW.EQ.0) CAYA=CAYW
C      IF (IDSTP.NE.12) GO TO 11
C      EMUA=0.0EQ
C      RHOA=RHOW
C      EMW=EMA
C      CAYW=CAYA
C      11 IF (RHOA.LE.0.0EQ) RHOA=1.0EQ
C      IF (EMA.LT.1.E-30) GO TO 44
C      WRITE (6,3) NK,EMA,CAYA,RHOA,EMUA,CONC
C      BHT=BH*(298.E0/TEMP)
C      IF (EMUA.LE.0.01) CH=0.0
C      RC=BHT*CH
C      A=1.E0+((RHOA/RHOW)*EMUA*CH)
C      AC=A*(1.E0/3.E0)
C      ADJUST EM,RHO AND CAY PER G. HANEL/ADVANCES IN GEOPHYS/1976
C      RHO=RHOW*((RHOA-RHOW)/A)
C      EM=EMW*((EMA-EMW)/A)
C      CAY=CAYW*((CAYA-CAYW)/A)
C      CAY=CAY/EM
C      INITIALIZE QUANTITIES USED TO HOLD RUNNING SUMMATIONS OVER
C      RADII FOR THE CURRENT COMPONENT
C      FSUMG=0.0EQ
C      CTSUM=0.0EQ
C      CSSUM=0.0EQ
C      CRSUM=0.0EQ
C      VOL=0.0EQ
C      OLISUM=0.0EQ
C      OL2SUM=0.0EQ
C      DO 13 J=1,IT
C      13 PSUM(J)=0.0EQ
C      PRINT HEADER IF DETAILED MIE RESULTS ARE TO BE PRINTED
C      IF (MORTE.EQ.12345) WRITE (6,5)
C      BEGIN ACTUAL LOOP OVER RADIUS INTERVALS FOR THE CURRENT NK VALUE
C      THIS LOOP IS THE ONE IN WHICH THE MIE CALCULATIONS ARE CALLED
C      INTERVALS ARE INDEXED BY I. THERE ARE NI SUCH INTERVALS.
C      DO 26 I=1,NI
C      NRADI=2
C      MERROR=0

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PTX0660
PTX0670
PTX0680
PTX0690
PTX0700
PTX0710
PTX0720
PTX0730
PTX0740
PTX0750
PTX0760
PTX0770
PTX0780
PTX0790
PTX0800
PTX0810
PTX0820
PTX0830
PTX0840
PTX0850
PTX0860
PTX0870
PTX0880
PTX0890
PTX0900
PTX0910
PTX0920
PTX0930
PTX0940
PTX0950
PTX0960
PTX0970
PTX0980
PTX0990
PTX1000
PTX1010
PTX1020
PTX1030
PTX1040
PTX1050
PTX1060
PTX1070
PTX1080
PTX1090
PTX1100
PTX1110
PTX1120
PTX1130
PTX1140
PTX1150
PTX1160
PTX1170
PTX1180
PTX1190
PTX1200
PTX1210
PTX1220

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+      IAPX)
      EM=SNGL(EMD)
      CAY=SNGL(CAYD)
      ALPHA=SNGL(ALPHAD)
      QT=SNGL(QTD)
      QS=SNGL(QSD)
      QR=SNGL(QRD)
      O1STAR=SNGL(O1STRD)
      O2STAR=SNGL(O2STRD)
      IF (TERROR=EQ.1) MERROR=MERROR+1
      KKI=1+NKG*1
      FKKI=F(KKI)
      IF (MQRTI=EQ.12345) WRITE (6,4) RIT,RR(1+1),FKK1,ALPHA,QT,QS,QR
      FKKIA=FKK1*PI*RIT*.2*EQ
      VOLHH=(VOLHH+4.188EQ*FKK1*RIT*.3*EQ)*D*0.5EQ
      OLIHH=(OLIH+FKKIA*QT*O1SIAR)*D*0.5EQ
      OL2HH=(OL2HH+FKKIA*QT*O2SIAR)*D*0.5EQ
      CTHH=(CTHH+QT*FKKIA)*D*.5EQ
      CSHH=(CSHH+QS*FKKIA)*D*.5EQ
      CRHH=(CRHH+QR*FKKIA)*D*.5EQ
      DO 15 J=1,IT
      PHH(J)=(PHH(J)+SNGL(P(J))*FKK1)*D*0.5EQ
15      CONTINUE
      FF=0.5EQ*D*(FKK+FKK1)
      NT=1
      C** DELI=0.0EQ
      N=1
16      NJ=NT
      NT=2*NT
      D=0.5EQ*D
      VOLGG=0.0EQ
      OL1GG=0.0EQ
      OL2GG=0.0EQ
      CTGG=0.0EQ
      CSGG=0.0EQ
      CRGG=0.0EQ
      FT=0.0EQ
      DO 17 J=1,IT
17      PGG(J)=0.0EQ
      C      NEXT LOOP HANDLES INTERMEDIATE PARTICLE SIZES..THOSE LYING BETWEEN
      C      RMIN AND RMAX FOR THE CURRENT INTERVAL WHOSE INDEX IS 1.
      DO 19 JG=1,NJ
      KK=1+(J-1)*NKG+(2*JG-1)*(NKG/NT)
      RIT=R(KK)*AC -(BC/AC)
      IF (RIT<LT*R(KK)-UR*R(KK)*LT*0.04EQ) RIT=R(KK)
      ALPHA=2.0EQ*PI*RIT/WAVE
      EMD=DBLE TEM)
      CAYD=DBLE (CAY)
      ALPHAD=DBLE (ALPHA)
      CALL MIEGX(EMD,CAYD,ALPHAD,QTD,QSD,QRD,P,O1STRD,O2STRD,IERROR,
+      IAPX)
      EM=SNGL(EMD)
      CAY=SNGL(CAYD)
      ALPHA=SNGL(ALPHAD)
      QT=SNGL(QTD)
      QS=SNGL(QSD)
      QR=SNGL(QRD)

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PT2X1800
PT2X1810
PT2X1820
PT2X1830
PT2X1840
PT2X1850
PT2X1860
PT2X1870
PT2X1880
PT2X1890
PT2X1900
PT2X1910
PT2X1920
PT2X1930
PT2X1940
PT2X1950
PT2X1960
PT2X1970
PT2X1980
PT2X1990
PT2X2000
PT2X2010
PT2X2020
PT2X2030
PT2X2040
PT2X2050
PT2X2060
PT2X2070
PT2X2080
PT2X2090
PT2X2100
PT2X2110
PT2X2120
PT2X2130
PT2X2140
PT2X2150
PT2X2160
PT2X2170
PT2X2180
PT2X2190
PT2X2200
PT2X2210
PT2X2220
PT2X2230
PT2X2240
PT2X2250
PT2X2260
PT2X2270
PT2X2280
PT2X2290
PT2X2300
PT2X2310
PT2X2320
PT2X2330
PT2X2340
PT2X2350
PT2X2360

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PT2X2370
PT2X2380
PT2X2390
PT2X2400
PT2X2410
PT2X2420
PT2X2430
PT2X2440
PT2X2450
PT2X2460
PT2X2470
PT2X2480
PT2X2490
PT2X2500
PT2X2510
PT2X2520
PT2X2530
PT2X2540
PT2X2550
PT2X2560
PT2X2570
PT2X2580
PT2X2590
PT2X2600
PT2X2610
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PT2X2660
PT2X2670
PT2X2680
PT2X2690
PT2X2700
PT2X2710
PT2X2720
PT2X2730
PT2X2740
PT2X2750
PT2X2760
PT2X2770
PT2X2780
PT2X2790
PT2X2800
PT2X2810
PT2X2820
PT2X2830
PT2X2840
PT2X2850
PT2X2860
PT2X2870
PT2X2880
PT2X2890
PT2X2900
PT2X2910
PT2X2920
PT2X2930

O1STAR=SNGL(O1STRD)
O2STAR=SNGL(O2STRD)
IF (IERROR.EQ.1) MERROR=MERROR+1
IF (MERROR.GT.10) GO TO 39
IF (MORTE.EQ.12345) WRITE (6,4) RIT,R(KK),F(KK),ALPHA,QT,Q5,QR
NRADI=NRADI+1
FKK=F(KK)
FKKA=FKK*PI*RIT**2.E0
VOLGG=4.1888E0*FKK*RIT**3.0E0+VOLGG
OL1GG=OL1GG+O1STAR*FKKA*QT
OL2GG=OL2GG+O2STAR*FKKA*QT
CTGG=CTGG+QT*FKKA
CSGG=CSGG+QS*FKKA
CRGG=CRGG+QR*FKKA
DO 18 J=1,IT
PGG(J)=PGG(J)+SNGL(PI(J))*FKK
CONTINUE
18
19 FT=FT+FKK
C ADD RESULTS ACCUMULATED DURING PREVIOUS HALVINGS TO THOSE FOUND
C FOR THE NEW RADII TREATED WITHIN THE LOOP OVER INDEX JG
VOLHHT=0.5E0*VOLHH+D*VOLGG
OL1HHT=0.5E0*OL1HH+D*OL1GG
OL2HHT=0.5E0*OL2HH+D*OL2GG
CTHHT=0.5E0*CTHH+D*CTGG
CSHHT=0.5E0*CSHH+D*CSGG
CRHHT=0.5E0*CRHH+D*CRGG
DO 20 J=1,IT
20 PHHT(J)=.5E0*PHH(J)+D*PGG(J)
FFT=.5E0*FF+D*FT
IF (CTHHT.LT.1.E-35) GO TO 22
DEL=ABS(VOLHHT-VOLHH)/ABS(VOLHHT)
C DELETE THE C** FROM COLS 1-3 BELOW AND ABOVE, AND DELETE THE
C FOLLOWING -IF- STATEMENT TO IMPLEMENT A DOUBLE CHECK FOR
C CONVERGENCE.
C** IF(DEL.GT.DELTA)GO TO 22
C** IF(DEL.LE.DELI)GO TO 24
C** DELI=DEL
IF (DEL.LE.DELTA) GO TO 21
GO TO 22
21 IF (N.GT.2) GO TO 24
C DO NOT ALLOW DEL LESS THAN DELTA EXIT UNLESS AT LEAST TWO
C HAVINGS HAVE BEEN DONE
22 IF (N.EQ.NHALV) GO TO 24
C MUST EXIT WHEN NHALV HALVINGS HAVE BEEN DONE EVEN IF THE DELTA
C CRITERION HAS NOT BEEN SATISFIED..SINCE NO MORE VALUES OF RADII
C ARE AVAILABLE.
FF=FFT
CRHH=CRHHT
OL1HH=OL1HHT
OL2HH=OL2HHT
CSHH=CSHHT
CTHH=CTHHT
VOLHH=VOLHHT
DO 23 J=1,IT
23 PHH(J)=PHHT(J)
N=N+1
GO TO 16

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24 FSUMG=FSUMG+FFT
   IF (N.EQ.NHALV) WRITE(6,124) I
   SUM QUANTITIES OVER ALL INTERVALS TREATED UP UNTIL NOW
   CTSUM=CTSUM+CIHHT
   CSSUM=CSSUM+CSHHT
   CRSUM=CRSUM+CRHHT
   VOL=VOL+VOLHHT
   OLISUM=OLISUM+OLIHT
   OL2SUM=OL2SUM+OL2HHT
   C AT THIS POINT, PSUM(I) IS THE RUNNING SUM OF THE AVG. INTENSITY
   C AS SUMMED OVER SIZES
   DO 25 J=1,IT
25 PSUM(J)=PSUM(J)+PHHT(J)
   WRITE (6,27) NK,I,NRAI,CIHHT
   NLINES=NLINES+NRAI
   C END LOOP OVER HALVING INTERVALS INDEXED BY I
26 CONTINUE
   C RENORMALIZE VALUES OF CTSUM, ETC.
   CTSUM=CTSUM/FSUMG
   CSSUM=CSSUM/FSUMG
   CRSUM=CRSUM/FSUMG
   VOL=VOL/FSUMG
   OLISUM=OLISUM/FSUMG
   OL2SUM=OL2SUM/FSUMG
   DO 28 J=1,IT
28 PSUM(J)=PSUM(J)/FSUMG
   C CALCULATE PARTICLE NUMBER DENSITY(N0. PER CC) AS DENSC
   DENSC=CONC/(RHOA*DRYVOL)
   C OVERRIDE CALCULATED VALUE OF DENSC WITH DENS IF LLLL =1
   IF (LLLL.EQ.1) DENSC=DENS
   C RECALCULATE CONC FROM OTHER INPUT DATA IF LLLL=1
   IF (LLLL.EQ.1) CONC=DENS*KHOA*DRYVOL
   C REPLACE DENS BY DENSC FOR LATER USE BY AGXPT3
   DENS=DENSC
   C WEIGHT CTSUM,ETC. BY NUMBER DENSITIES (DENSC) FOR THIS COMPONENT
   CTSUM=CTSUM*DENSC
   CSSUM=CSSUM*DENSC
   CRSUM=CRSUM*DENSC
   VOL=VOL*DENSC
   OLISUM=OLISUM*DENSC
   OL2SUM=OL2SUM*DENSC
   DO 29 J=1,IT
29 PSUM(J)=PSUM(J)*DENSC
   C NOW, SUM OVER COMPONENTS INDEXED BY NK
   C CONCT IS THE TOTAL DRY-AEROSOL CONCENTRATION IN MG PER CC
   CONCT=CONCT+I.E3*CONC
   DENST=DENST+DENSC
   OLSTAR=OLISUM+OLSTAR
   OM2=OL2SUM+OM2
   CTSUM=CTSUM+CTSUM
   C AT THIS POINT, CTSUM IS THE TOTAL EXTINCTION CROSS SECTION
   C (IN SQ. MICRONS) AS SUMMED OVER ALL COMPONENTS WHICH
   C HAVE BEEN DEALT WITH THUS FAR
   CSSUM=CSSUM+CSSUM
   CRSUM=CRSUM+CRSUM
   DO 30 J=1,IT
30 PSUM(J)=PSUM(J)+PSUMT(J)

```

PT2X2940  
 PT2X2950  
 PT2X2960  
 PT2X2970  
 PT2X2980  
 PT2X2990  
 PT2X3000  
 PT2X3010  
 PT2X3020  
 PT2X3030  
 PT2X3040  
 PT2X3050  
 PT2X3060  
 PT2X3070  
 PT2X3080  
 PT2X3090  
 PT2X3100  
 PT2X3110  
 PT2X3120  
 PT2X3130  
 PT2X3140  
 PT2X3150  
 PT2X3160  
 PT2X3170  
 PT2X3180  
 PT2X3190  
 PT2X3200  
 PT2X3210  
 PT2X3220  
 PT2X3230  
 PT2X3240  
 PT2X3250  
 PT2X3260  
 PT2X3270  
 PT2X3280  
 PT2X3290  
 PT2X3300  
 PT2X3310  
 PT2X3320  
 PT2X3330  
 PT2X3340  
 PT2X3350  
 PT2X3360  
 PT2X3370  
 PT2X3380  
 PT2X3390  
 PT2X3400  
 PT2X3410  
 PT2X3420  
 PT2X3430  
 PT2X3440  
 PT2X3450  
 PT2X3460  
 PT2X3470  
 PT2X3480  
 PT2X3490  
 PT2X3500

```

VOL=VOL*1.E-12
TVOL IS THE TOTAL VOLUME (IN CM*3) OCCUPIED BY THE AEROSOL
PARTICLES. TVOL IS NOT ACTUALLY USED IN THIS VERSION OF
PROGRAM AGAUS.
TVOL=VOL+TVOL
EMASS=VOL*RHO
TMASS=TMASS+EMASS
KEXOLD=KEXIT
KEXIT=CTSUM*1.E-3
KEXIT=KEXIT-KEXOLD
WRITE (6,31) NK,VOL,EMASS,KEXIT
VPF(VOL) IS THE VOLUME PACKING FRACTION: THAT IS, THE FRACTION
OF EACH CC OF SPACE WHICH IS FILLED BY AEROSOL MATERIAL BELONGING
TO THE CURRENT COMPONENT NK.
TMASS IS THE TOTAL MASS OF AEROSOL FOUND IN 1 CC OF SPACE.
EMASS IS THE MASS OF AEROSOL MATERIAL PER CC ASSOCIATED WITH
THE CURRENT COMPONENT NK.
KEXIT IS THE EXTINCTION COEF. (PER KM) WHICH IS ASSOCIATED WITH
THE CURRENT COMPONENT--AS IF IT ALONE WERE PRESENT.
KEXIT IS THE SUM OF THE KEXIT'S OVER ALL COMPONENTS.
END LOOP OVER AEROSOL COMPONENTS INDEXED BY NK.
IF (NINDX.GT.1) WRITE (6,42) NK
IF (MORTE.EQ.12345) WRITE (6,43)
32 CONTINUE
IF (NINDX.GT.1) WRITE (6,33) TMASS,KEXIT
WRITE (6,34) N LINES
DENS=DENST
NRAD=N LINES
NOW, PERFORM THE FINAL RENORMALIZATIONS TO OBTAIN CTSUM, ETC.
VALUES REPRESENTATIVE OF A SINGLE AVERAGE PARTICLE.
CTSUM BECOMES THE EXTINCTION CROSSSECTION IN SQ. MICROMETERS PER
AVERAGE PARTICLE. THE OTHER QUANTITIES CARRY SIMILAR MEANINGS.
DO 35 J=1,11
35 PSUM(J)=PSUM(J)/DENST
OLSTAR=OLSTAR/CTSUNT
OM2=OM2/CTSUNT
IF (IAPX.GT.0) WRITE (6,36) OLSTAR,OM2
THE FOLLOWING 2 STMTS ARE FOR THE GHG ANALYTIC PHASE FUNCTION.
IF (IAPX.GT.0) OL(2)=OLSTAR
IF (IAPX.GT.0) OL(3)=OM2
CTSUM=CTSUNT/DENST
CSSUM=CSSUNT/DENST
CRSUM=CRSUNT/DENST
THE FOLLOWING STMT IS FOR THE GHG ANALYTIC PHASE FUNCTION.
IF (IAPX.GT.0) OL(1)=CSSUM/CTSUNT
CALCULATE ATTENUATION COEFFS. IN SQ. METERS PER MILLIGRAM
CATTN=1.E-12*KEXIT/TMASS
CATTN=CATTN*1.E-12/CONCT
WRITE (6,37) CATTN
IF (RELHUM.GT.1.0) WRITE (6,38) CATTN
GO TO 41
39 WRITE (6,40)
STOP
44 WRITE (6,45) EMA
STOP
41 RETURN
2 FORMAT (4F10.6,E15.7)

```

PT2X3510  
PT2X3520  
PT2X3530  
PT2X3540  
PT2X3550  
PT2X3560  
PT2X3570  
PT2X3580  
PT2X3590  
PT2X3600  
PT2X3610  
PT2X3620  
PT2X3630  
PT2X3640  
PT2X3650  
PT2X3660  
PT2X3670  
PT2X3680  
PT2X3690  
PT2X3700  
PT2X3710  
PT2X3720  
PT2X3730  
PT2X3740  
PT2X3750  
PT2X3760  
PT2X3770  
PT2X3780  
PT2X3790  
PT2X3800  
PT2X3810  
PT2X3820  
PT2X3830  
PT2X3840  
PT2X3850  
PT2X3860  
PT2X3870  
PT2X3880  
PT2X3890  
PT2X3900  
PT2X3910  
PT2X3920  
PT2X3930  
PT2X3940  
PT2X3950  
PT2X3960  
PT2X3970  
PT2X3980  
PT2X3990  
PT2X4000  
PT2X4010  
PT2X4020  
PT2X4030  
PT2X4040  
PT2X4050  
PT2X4060  
PT2X4070

```

3  FORMAT (I10,6H INDX=,I3,4H M= ,F10.6,6H K = -,F10.6,9H1.  MASS ,
+
+ 10H DENSITY = ,F8.6,
+ 17H GROWTH FACTOR = ,F8.4,9H. CONC = ,IPE12.5,7H GM/CC/)
4  FORMAT (I1X,F10.5,6(2X,IPE11.5))
5  FORMAT (//54H R(MICRONS) DRY RADIUS N(R) MIE SIZE
+ ,36HQ (EXT) Q(RADAR)/)
9  FORMAT (I10,39H INDEX OF REFRACTION FOR PURE WATER IS: ,F8.6,
+ 3H -,F8.6,1H1//,1X,25H MASS DENSITY OF WATER AT ,F6.2,
+ 11H DEG C IS: ,F8.2,6H GM/CC)
24  FORMAT (/52H *** CONVERGENCE LEVEL NOT REACHED FOR INTERVAL NO. ,
+ 13,4H **/)
27  FORMAT (I1H ,19H FOR COMPONENT NO. ,I3,15H INTERVAL NO. ,I3,1H ,14,
+ 43H RADII WERE USED. CONTRIBUTION TO CTSUM = ,IPE12.6)
31  FORMAT (I10,19H FOR COMPONENT NO. ,I2,12H : VPF = ,IPE12.5,
+ 24H MASS CONCENTRATION = ,E12.5,21H GM/CC. KEAT =
+ E12.5,7H PER KM)
33  FORMAT (I10,28H TOTAL MASS CONCENTRATION = ,IPE12.5,7H GM/CC:,
+ 15H TOTAL KEAT = ,E12.5,7H PER KM)
34  FORMAT (/1X,32H TOTAL NUMBER OF RADII USED WAS ,I5)
36  FORMAT (/16H OMEGA SUB-1 = ,IPE20.13/,16H OMEGA SUB-2 = ,
+ IPE20.13/)
37  FORMAT (I10,21H ATTENUATION COEF. = ,IPE12.5,12H SQ-METERS/,
+ 33H MILLIGRAM OF DRY AEROSOL MATERIAL)
38  FORMAT (I10,21H ATTENUATION COEF. = ,IPE12.5,12H SQ-METERS/,
+ 33H MILLIGRAM OF WET AEROSOL MATERIAL)
40  FORMAT (///47H *** EXECUTION TERMINATING DUE TO MORE THAN TEN,
+ 30H ERRORS IN MIE-SUBROUTINE ***)
42  FORMAT (I10//,1X,10X,30(IH*),33H END OF AEROSOL COMPONENT CYCLE ,
+ 7HNUMBER ,I3,2X,30(IH*)//)
43  FORMAT (I10)
45  FORMAT (///,1X,11H**** EMA (,F10.6,20H) IS EITHER ZERO OR ,
+ 35HNEGATIVE - PROGRAM TERMINATED ****)
END
PT2X4080
PT2X4090
PT2X4100
PT2X4110
PT2X4120
PT2X4130
PT2X4140
PT2X4150
PT2X4160
PT2X4170
PT2X4180
PT2X4190
PT2X4200
PT2X4210
PT2X4220
PT2X4230
PT2X4240
PT2X4250
PT2X4260
PT2X4270
PT2X4280
PT2X4290
PT2X4300
PT2X4310
PT2X4320
PT2X4330
PT2X4340
PT2X4350
PT2X4360
PT2X4370
PT2X4380
PT2X4390
PT2X4400

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SUBROUTINE AGXPT3(CTSUM,CSSUM,CRSUM,GNU,DENS,NINDX,NUNIT,IANG,
+ ITOT,IAPX)
PT3X0100
PT3X0110
PT3X0120
PT3X0130
PT3X0140
PT3X0150
PT3X0160
PT3X0170
PT3X0180
PT3X0190
PT3X0200
PT3X0210
PT3X0220
PT3X0230
PT3X0240
PT3X0250
PT3X0260
PT3X0270
PT3X0280
PT3X0290
PT3X0300
PT3X0310
PT3X0320
PT3X0330
PT3X0340
PT3X0350
PT3X0360
PT3X0370
PT3X0380
PT3X0390
PT3X0400
PT3X0410
PT3X0420
PT3X0430
PT3X0440
PT3X0450
PT3X0460
PT3X0470
PT3X0480
PT3X0490
PT3X0500
PT3X0510
PT3X0520
PT3X0530
PT3X0540
PT3X0550
PT3X0560
PT3X0570
PT3X0580
PT3X0590
PT3X0600
PT3X0610
PT3X0620
PT3X0630
PT3X0640
PT3X0650

DIMENSION F(513),R(513),C(100),PSUM(300),RR(9),DR(8)
DIMENSION PL(100,100),OL(100),RMS(100),PC(100),H(100),SCAT(100)
COMMON /BK2/PL,OL,RMS,PC,H,ALBDO,LLLL,NCRDS,IT,ITT,NR,DI
COMMON /BK3/F,R,PSUM,SCAT,RR,DR,WAVE,EM,CAY,EMM,PI,IDSTP,
I MORTE,NKG,NHALV,NI
ALBDO=CSSUM/CTSUM
CAYNG=CAY
PFAC=1.0/PI
FUNCTIONS=SFAC*PSUM(J)
PSUM(J)=PSUM(J)*PFAC
IF ((NCRDS*EQ.2)*OR.(NCRDS*EQ.3)).AND.((ITOT*EQ.1).OR.(ITOT*EQ.3)
+ ).AND.((IAPX*EQ.0)) WRITE (NUNIT,3) SCAT(J),PSUM(J),C(J),J
15 CONTINUE
IF (NINDX*GE.2) WRITE (6,12)
IF (IAPX*EQ.0) WRITE (6,10)
WRITE (6,4) IDSTP,WAVE,EM,CAYNG,CTSUM,CSSUM,ALBDO
C CONVERT AVG. CROSS-SECTIONS TO COEFFICIENTS (PER KM)
CTSUM=CTSUM*1.0E-3*DENS
CSSUM=CSSUM*1.0E-3*DENS
CRSUM=CRSUM*1.0E-3*DENS
WRITE (6,13) CTSUM,CSSUM,CRSUM
WRITE (6,14) GNU,DENS
IF (ITT*LT.2) GO TO 21
IF (IANG*EQ.3) GO TO 18
C WRITE PHASE FUNCTION AT EQUAL ANGULAR INCREMENTS
WRITE (6,1)
WRITE (6,6)
DO 16 J=1,IT,4
K=J+3
IF (K*GT.IT) K=IT
16 WRITE (6,9) (H(I),PSUM(I),I=J,K)
C WRITE SCATTERING FRACTIONS AT EQUAL ANGULAR INCREMENTS
WRITE (6,2)
WRITE (6,7)
DO 17 J=1,IT,4
K=J+3
IF (K*GT.IT) K=IT
17 WRITE (6,9) (H(I),SCAT(I),I=J,K)
GO TO 21
18 WRITE (6,1)
WRITE (6,5)
C WRITE PHASE FUNCTION AT GAUSS-LEGENDRE QUADRATURE ANGLES
DO 19 J=1,IT,4
K=J+3
IF (K*GT.IT) K=IT
19 WRITE (6,8) (C(I),PSUM(I),I=J,K)
WRITE (6,11)

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C      CALL GAUS(PSUM,NUNIT,ITOT)
C      ROUTINE GAUS GENERATES AND PRINTS/PUNCHES THE LEGENDRE
C      EXPANSION COEFS (OMEGAS) FOR THE PHASE FUNCTION.
C      CHECK TO SEE IF SNG SCAT ALBEDO (ALBDO) COMPUTED DIRECTLY
C      FROM CROSS-SECTIONS AGREES WITH THAT FOUND FROM THE LEGENDRE
C      EXPANSION OF PHASE-FUNCTION.
      IF ((ABS(TOL(1)-ALBDO)/ALBDO).GT.1.E-4) WRITE (6,20)
21 RETURN
      1 FORMAT (//1H,50X,14HPHASE FUNCTION/,1X,38X,40H(INTEGRAL NORMALIZE
      +D TO 4 PI OMEGA ZERO)/)
      2 FORMAT (1H, //,37X,43HSCATTERING FRACTIONS ( ACT NORMALIZATION)/)
      3 FORMAT (3(E12.6,1X),15)
      4 FORMAT (1H0,41H DISTRIBUTION WAVELENGTH REFRACTIVE,9X,
      + 20HEXTINCTION X SECTION,8X,20HSCATTERING X SECTION,12X,5HALBDO/1HPT3X0770
      + ,6X,4HTYPE,6X,9H(MICRONS),8X,5HINDEX,16X,12H(SQ MICRONS),13X,
      + 12H(SQ MICRONS)/1H,19,4X,F13.4,F10.4,2H(1,F7.4,2H1),
      + 1P3E25.14)
      5 FORMAT (1H0,3X,4(5H MU,8X,17HPHASE FUNCTION //)
      6 FORMAT (1H0,18X,4(20H ANGLE PF-VALUE //)
      7 FORMAT (1H0,18X,4(20H ANGLE SCAT //)
      8 FORMAT (1H,4(F13.9,E17.10))
      9 FORMAT (1H,18X,4(1X,F6.2,1X,E12.7))
10 FORMAT (1H1)
11 FORMAT (1H0/,1X,25X,1HL,20X,16HL-TH COEFFICIENT,23X,5HRMS ,
      + 9HDEVIATION/)
12 FORMAT (52H THIS IS A MIXED CASE * SUBSEQUENT REFRACTIVE INDEX ,
      + 34HPRINT-OUTS ARE NOT GENERALLY VALID/)
13 FORMAT (1H0,10H K(EXT) = ,1PE13.7,11H: K(SCA) = ,E13.7,
      + 11H: K(RAD) = ,E13.7,11H ALL PER KM/)
14 FORMAT (1/14H WAVENUMBER = ,1PE12.6,15H CM-1,5X,10HDENSITY = ,E12.6,PT3X0950
      + 17H PARTICLES PER CC/)
20 FORMAT (//51H *** WARNING *** ORDER OF QUADRATURE IS TOO SMALL , PT3X0970
      + 38HFOR GOOD PHASE FUNCTION REPRESENTATION//12H *** VALUES PT3X0980
      + ,55HOF ALBDO AND OL(1) DISAGREE BY MORE THAN .01 PERCENT **PT3X0990
      + ,34HLARGEN VALUE OF 'IT' IS NEEDED **/)
      END
PT3X0660
PT3X0670
PT3X0680
PT3X0690
PT3X0700
PT3X0710
PT3X0720
PT3X0730
PT3X0740
PT3X0750
PT3X0760
PT3X0770
PT3X0780
PT3X0790
PT3X0800
PT3X0810
PT3X0820
PT3X0830
PT3X0840
PT3X0850
PT3X0860
PT3X0870
PT3X0880
PT3X0890
PT3X0900
PT3X0910
PT3X0920
PT3X0930
PT3X0940
PT3X0950
PT3X0960
PT3X0970
PT3X0980
PT3X0990
PT3X1000
PT3X1010

```



```

SUBROUTINE MIEGX(EM,CAY,ALPHA,SGT,SGS,SGR,P,OISTAR,O2STAR,IERROR,
1 IAPX)
C TO CALCULATE BESSEL FUNCTIONS OF THE SECOND KIND ALSO
C REMOVE THE C.S FROM STATEMENTS CIRCA 124, 179 AND
C CHANGE THE 'DO' PARAMETERS FOR STMT. TO: DO 190 K=1,2.
IMPLICIT DOUBLEPRECISION(A-H,O-Z)
REAL PL,OL,RMS,PC,C,H,ALRDO,P,SINGL
DIMENSION C(100),EYE1(100),EYE2(100),EYE3(100),EYE4(100),P(100)
COMPLEX*16 A(1000),ACAPN,ZNUM,ZDEN,ZPDT,ZRPDT,ZAN,ZANP,Y,RF,RRF,
1 RRF,WM1,FNA,FNB,TC1,FNAP,FNBP,FNAPP,FNBPP,TC2,WFN(2)
DIMENSION PL(100,100),OL(100),RMS(100),PC(100),H(100)
COMMON /BK2/PL,OL,RMS,PC,C,H,ALBDO,LLLL,NCRDS,IT,ITT,NRADI
EQUIVALENCE (WFN(1),TA(1)),(FNA,TB(1)),(FNB,TC(1)),(FNAP,TD(1))
EQUIVALENCE (FNBP,TE(1)),(FNAPP,TF(1)),(FNBPP,TG(1))
EQUIVALENCE (ELTRMX(1),PL(1)),(PI(1),PL(1601)),(TAU(1),PL(2401))
EQUIVALENCE (A(1),PL(3201))
X=ALPHA
IERROR=0
PI1=3.141592653589790+00
CAYE=CAY*EM
NMX=0
S=1.00
RF=DCMLPX(EM,-CAYE)
NMX=FIX(X*(EM+CAYE))+9
RRF=1.00/RF
RX=1.007X
RRFX=RRF*RX
DO 1 J=1,IT
PI(1,J)=0.00
PI(2,J)=1.00
TAU(1,J)=0.00
TAU(2,J)=C(J)
1 CONTINUE
T(1)=DCOS(X)
T(2)=DSIN(X)
WM1=DCMLPX(T(1),-T(2))
WFN(1)=DCMLPX(T(2),T(1))
WFN(2)=RX*WFN(1)-WM1
T(1)=CAYE*X
N=1
NDIM=1000
IF (NMX*LT*NDIM) NDELTA=NMX
IF (NMX*GT*NDIM) NDELTA=NDIM
NMX=0
IF (N*EQ.1) GO TO 4
2 EN=DFLOAT(N)
T(1)=2.00*EN-1.00
T(2)=EN-1.00
T(3)=2.00*EN+1.00
DO 3 J=1,IT
PI1J=PI(1,J)
PI2J=PI(2,J)
CJ=C(J)
C THE FOLLOWING STMT IS FOR THE GHG ANALYTIC PHASE FUNCTION.

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```

MEGX0100
MEGX0110
MEGX0120
MEGX0130
MEGX0140
MEGX0150
MEGX0160
MEGX0170
MEGX0180
MEGX0190
MEGX0200
MEGX0210
MEGX0220
MEGX0230
MEGX0240
MEGX0250
MEGX0260
MEGX0270
MEGX0280
MEGX0290
MEGX0300
MEGX0310
MEGX0320
MEGX0330
MEGX0340
MEGX0350
MEGX0360
MEGX0370
MEGX0380
MEGX0390
MEGX0400
MEGX0410
MEGX0420
MEGX0430
MEGX0440
MEGX0450
MEGX0460
MEGX0470
MEGX0480
MEGX0490
MEGX0500
MEGX0510
MEGX0520
MEGX0530
MEGX0540
MEGX0550
MEGX0560
MEGX0570
MEGX0580
MEGX0590
MEGX0600
MEGX0610
MEGX0620
MEGX0630
MEGX0640
MEGX0650

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IF (IAPX.GT.0) CJ=1.00
S2T=(1.0D+00-CJ*CJ)
PI(3,J)=T(1)*PI2J-CJ-EN*PI(1,J)/T(2)
TAU(3,J)=CJ*(PI(3,J)-PI(1,J)-T(1)*S2T*PI2J+TAU(1,J)
3 CONTINUE
WMI=WFN(1)
WFN(1)=WFN(2)
WFN(2)=T(1)*RX*WFN(1)-WMI
4 CONTINUE
C CALCULATE RATIO OF BESSEL FMS OF CONSECUTIVE ORDER
IF (N.LT.(NMX+1)) GO TO 9
NMX=NMX+NDELTA
NMIN=NMX+1-NDELTA
V=DFLOAT(NMX)+0.500
Y=RF*X
ZANP=2.0D3/Y
ZNUM=ZANP*V
ZPDT=ZNUM
V=V+1.0D3
ZDEN=ZANP*V
ZNUM=ZDEN-1.0D/ZNUM
ZHPDT=ZNUM/ZDEN
ZPDT=ZHPDT*ZPDT
IF (DABS(DREAL(ZRPDT)-1.0D).LT.1.0D-10) GO TO 7
IF (V.LT.20000.00) GO TO 6
WRITE (6,1000) ALPHA,EM,CAY
IERROR=1
GO TO 20
6 V=V+1.0D3
ZAN=ZANP*V
ZNUM=ZAN-1.0D/ZNUM
ZDEN=ZAN-1.0D/ZDEN
GO TO 5
7 CONTINUE
J=NMX
8 JJ=J-NMX+NDELTA
A(JJ)=-IDFLOAT(J)/Y+ZPDT
J=J-1
IF (J.LT.NMIN) GO TO 9
ZPDT=(2.0D+DFLOAT(J)+1.0D)/Y-1.0D/ZPDT
GO TO 8
9 CONTINUE
J=N-NMX+NDELTA
ACAPN=A(J)
IF (N.GT.1) GO TO 11
THIS PART FOR N EQUAL 1 ONLY
TC1=ACAPN*RRF*RX
TC2=ACAPN*RRF*RX
FNA=(TC1*TA(3)-TA(1))/(TC1*WFN(2)-WFN(1))
FNB=(TC2*TA(3)-TA(1))/(TC2*WFN(2)-WFN(1))
FNAP=FNA
FNBP=FNB
T(1)=1.500
TB(1)=T(1)*TB(1)
TB(2)=T(1)*TB(2)
TC(1)=T(1)*TC(1)
TC(2)=T(1)*TC(2)

```

MEGX0660  
MEGX0670  
MEGX0680  
MEGX0690  
MEGX0700  
MEGX0710  
MEGX0720  
MEGX0730  
MEGX0740  
MEGX0750  
MEGX0760  
MEGX0770  
MEGX0780  
MEGX0790  
MEGX0800  
MEGX0810  
MEGX0820  
MEGX0830  
MEGX0840  
MEGX0850  
MEGX0860  
MEGX0870  
MEGX0880  
MEGX0890  
MEGX0900  
MEGX0910  
MEGX0920  
MEGX0930  
MEGX0940  
MEGX0950  
MEGX0960  
MEGX0970  
MEGX0980  
MEGX0990  
MEGX1000  
MEGX1010  
MEGX1020  
MEGX1030  
MEGX1040  
MEGX1050  
MEGX1060  
MEGX1070  
MEGX1080  
MEGX1090  
MEGX1100  
MEGX1110  
MEGX1120  
MEGX1130  
MEGX1140  
MEGX1150  
MEGX1160  
MEGX1170  
MEGX1180  
MEGX1190  
MEGX1200  
MEGX1210  
MEGX1220

```

DO 10 J=1,IT
  TAU2J=TAU(2,J)
  ELTRMX(1,J,1)=TB(1)+TC(1)*TAU2J
  ELTRMX(2,J,1)=TB(2)+TC(2)*TAU2J
  ELTRMX(3,J,1)=TC(1)+TB(1)*TAU2J
  ELTRMX(4,J,1)=TC(2)+TB(2)*TAU2J
  ELTRMX(1,J,2)=TB(1)-TC(1)*TAU2J
  ELTRMX(2,J,2)=TB(2)-TC(2)*TAU2J
  ELTRMX(3,J,2)=TC(1)-TB(1)*TAU2J
  ELTRMX(4,J,2)=TC(2)-TB(2)*TAU2J
10 CONTINUE
  QEXT=2.00*(TB(1)+TC(1))
  QSCAT=(TB(1)*TB(1)+TB(2)*TB(2)+TC(1)*TC(1)+TC(2)*TC(2))/0.7500
  CTBR05=0.00
  SUMW=0.00
  OZSTAR=0.00
  SUMRR=2.00*(TB(1)-TC(1))
  SUMRI=2.00*(TB(2)-TC(2))
  N=2
  GO TO 2
21 CONTINUE
  TCI=ACAPN*RRF+EN*RX
  TC2=ACAPN*RF+EN*RX
  FNA=(TC1*TA(3)-TA(1))/(TC1*WFN(2)-WFN(1))
  FNB=(TC2*TA(3)-TA(1))/(TC2*WFN(2)-WFN(1))
  T(5)=EN
  T(4)=T(1)/(T(5)*T(2))
  T(2)=(T(2)*(T(5)+1.00))/T(5)
  CTBR05=CTBR05+T(2)*(TD(1)*TB(1)+TD(2)*TB(2)+TE(1)*TC(1)+TE(2)*
1 TC(2))+T(4)*(TD(1)*TE(1)+TD(2)*TE(2))
  S=-S
  SUMRR=SUMRR+S*T(3)*(TB(1)-TC(1))
  SUMRI=SUMRI+S*T(3)*(TB(2)-TC(2))
  O1STAR CALCULATION
  SUMW=SUMW+(TB(1)*Td(1)+TB(2)*Td(2)+TC(1)*TE(1)+TC(2)*TE(2))*T(2)*
1 4.00+4.00*T(4)*(TD(1)*TE(1)+TD(2)*TE(2))
  IF (N*LT.3) GO TO 12
  O2STAR CALCULATION
  F1=TF(1)*TF(1)+TF(2)*TF(2)+TG(1)*TG(1)+TG(2)*TG(2)
  F2=TB(1)*TB(1)+TB(2)*TB(2)+TC(1)*TC(1)+TC(2)*TC(2)
  F3=TD(1)*TD(1)+TD(2)*TD(2)+TE(1)*TE(1)+TE(2)*TE(2)
  ENL1=EN-1.00
  CUF1=2.500*(EN-2.00)*ENL1-3.00**2.00*(2.00*EN-3.00)/(EN-2.00)*
1 ENL1*(2.00*EN-1.00)*(2.00*EN-5.00)
  CUF2=7.500*(EN-2.00)*(EN+1.00)/(2.00*EN-1.00)
  CUF3=15.000/ENL1
  O2STAR=O2STAR*CUF1*F1+CUF2*F2+CUF3*F3
12 CONTINUE
  QEXT=QEXT+T(3)*(TB(1)+TC(1))
  T(4)=TB(1)*TB(1)+TB(2)*TB(2)+TC(1)*TC(1)+TC(2)*TC(2)
  Q5CAT=Q5CAT+T(3)*f(4)
  T(2)=EN*(EN+1.00)
  T(1)=T(3)/T(2)
  K=(N/2)*2
  DO 13 J=1,IT
  P13J=P1(3,J)
  TAU3J=TAU(3,J)

```

MEGX1230  
 MEGX1240  
 MEGX1250  
 MEGX1260  
 MEGX1270  
 MEGX1280  
 MEGX1290  
 MEGX1300  
 MEGX1310  
 MEGX1320  
 MEGX1330  
 MEGX1340  
 MEGX1350  
 MEGX1360  
 MEGX1370  
 MEGX1380  
 MEGX1390  
 MEGX1400  
 MEGX1410  
 MEGX1420  
 MEGX1430  
 MEGX1440  
 MEGX1450  
 MEGX1460  
 MEGX1470  
 MEGX1480  
 MEGX1490  
 MEGX1500  
 MEGX1510  
 MEGX1520  
 MEGX1530  
 MEGX1540  
 MEGX1550  
 MEGX1560  
 MEGX1570  
 MEGX1580  
 MEGX1590  
 MEGX1600  
 MEGX1610  
 MEGX1620  
 MEGX1630  
 MEGX1640  
 MEGX1650  
 MEGX1660  
 MEGX1670  
 MEGX1680  
 MEGX1690  
 MEGX1700  
 MEGX1710  
 MEGX1720  
 MEGX1730  
 MEGX1740  
 MEGX1750  
 MEGX1760  
 MEGX1770  
 MEGX1780  
 MEGX1790

```

      ELTRMX(1,J,1)=ELTRMX(1,J,1)+T(1)*(TB(1)*PI3J+TC(1)*TAU3J)
      ELTRMX(2,J,1)=ELTRMX(2,J,1)+T(1)*(TB(2)*PI3J+TC(2)*TAU3J)
      ELTRMX(3,J,1)=ELTRMX(3,J,1)+T(1)*(TC(1)*PI3J+TB(1)*TAU3J)
      ELTRMX(4,J,1)=ELTRMX(4,J,1)+T(1)*(TC(2)*PI3J+TB(2)*TAU3J)
      IF (K*EQ*N) GO TO 130
      C*
      ELTRMX(1,J,2)=ELTRMX(1,J,2)+T(1)*(TB(1)*PI3J-TC(1)*TAU3J)
      ELTRMX(2,J,2)=ELTRMX(2,J,2)+T(1)*(TB(2)*PI3J-TC(2)*TAU3J)
      ELTRMX(3,J,2)=ELTRMX(3,J,2)+T(1)*(TC(1)*PI3J+TB(1)*TAU3J)
      ELTRMX(4,J,2)=ELTRMX(4,J,2)+T(1)*(TC(2)*PI3J+TB(2)*TAU3J)
      GO TO 140
      C*
      ELTRMX(1,J,2)=ELTRMX(1,J,2)+T(1)*(-TB(1)*PI3J+TC(1)*TAU3J)
      ELTRMX(2,J,2)=ELTRMX(2,J,2)+T(1)*(-TB(2)*PI3J+TC(2)*TAU3J)
      ELTRMX(3,J,2)=ELTRMX(3,J,2)+T(1)*(-TC(1)*PI3J+TB(1)*TAU3J)
      ELTRMX(4,J,2)=ELTRMX(4,J,2)+T(1)*(-TC(2)*PI3J+TB(2)*TAU3J)
      C*
      13 CONTINUE
      IF (N*LT*5) GO TO 14
      IF (T(4)*LT*1.0D-10) GO TO 16
      14 N=N+1
      DO 15 J=1,IT
      PI(1,J)=PI(2,J)
      PI(2,J)=PI(3,J)
      TAU(1,J)=TAU(2,J)
      TAU(2,J)=TAU(3,J)
      15 CONTINUE
      FNAPP=FNAP
      FNBP=FNBP
      FNAP=FNA
      FNBP=FNBP
      GO TO 2
      16 CONTINUE
      WRITE (6,800) N
      DO 18 J=1,IT
      DO 18 K=1,1
      DO 17 I=1,4
      T(I)=ELTRMX(1,J,K)
      17 CONTINUE
      ELTRMX(1,J,K)=T(3)*T(3)+T(4)*T(4)
      ELTRMX(2,J,K)=T(1)*T(1)+T(2)*T(2)
      ELTRMX(3,J,K)=T(1)*T(3)+T(2)*T(4)
      ELTRMX(4,J,K)=T(2)*T(3)+T(4)*T(1)
      18 ELTRMX(2,1,J) IS THE VERTICAL COMPONENT SCATTERING 11 (EYE1)
      ELTRMX(1,1,J) IS THE HORIZONTAL COMPONENT SCATTERING 12
      DO 19 J=1,IT
      EYE1(J)=ELTRMX(2,J,1)
      EYE2(J)=ELTRMX(1,J,1)
      EYE3(J)=ELTRMX(3,J,1)
      EYE4(J)=-1.0D*ELTRMX(4,J,1)
      P(J)=SNGL((EYE1(J)+EYE2(J))/2.0D)
      19 CONTINUE
      T(1)=2.0D*RX*2.0D
      SGT=QEXT*T(1)
      SGS=QSCAT*T(1)
      CTBROS=2.0D*CTBROS*T(1)
      O1STAR=3.0D*SUMW/(X*X*SGT)
      O2STAR=4.0D*O2STAR/(X*X*SGT)
      SGR=(SUMRR*SUMRR+SUMRI*SUMRI)*RX*RX
      20 RETURN

```

MEGX1800  
 MEGX1810  
 MEGX1820  
 MEGX1830  
 MEGX1840  
 MEGX1850  
 MEGX1860  
 MEGX1870  
 MEGX1880  
 MEGX1890  
 MEGX1900  
 MEGX1910  
 MEGX1920  
 MEGX1930  
 MEGX1940  
 MEGX1950  
 MEGX1960  
 MEGX1970  
 MEGX1980  
 MEGX1990  
 MEGX2000  
 MEGX2010  
 MEGX2020  
 MEGX2030  
 MEGX2040  
 MEGX2050  
 MEGX2060  
 MEGX2070  
 MEGX2080  
 MEGX2090  
 MEGX2100  
 MEGX2110  
 MEGX2120  
 MEGX2130  
 MEGX2140  
 MEGX2150  
 MEGX2160  
 MEGX2170  
 MEGX2180  
 MEGX2190  
 MEGX2200  
 MEGX2210  
 MEGX2220  
 MEGX2230  
 MEGX2240  
 MEGX2250  
 MEGX2260  
 MEGX2270  
 MEGX2280  
 MEGX2290  
 MEGX2300  
 MEGX2310  
 MEGX2320  
 MEGX2330  
 MEGX2340  
 MEGX2350  
 MEGX2360

MEGX2370  
MEGX2380  
MEGX2390  
MEGX2400

C 1000 FORMAT (52H V GT 20000 ERROR IN CONTINUED FRACTIONS MIE ROUTINE,  
--1 11H... ALPHA =,D12.6,6H EM = ,D12.6,7H CAY = ,D12.6/)  
END

```

SUBROUTINE GAUS(F,NUNIT,IOT)
  DIMENSION C(100),F(100)
  DIMENSION PL(100,100),OL(100),RMS(100),PC(100),H(100)
  COMMON /BK2/PL,OL,RMS,PC,C,H,ALBD0,LLLL,NCRDS,IT,ITT,NRADI
  C THE FOLLOWING STEPS CALCULATE THE LEGENDRE POLYNOMIALS PL(,)
  C WHICH WILL BE USED BY SUBROUTINE GAUS IN FINDING THE GAUSS-
  C LEGENDRE EXPANSION COEFFICIENTS FOR THE PHASE FUNCTION.
  DO 9 I=1,IT
    PL(I,I)=1.0E+00
  9 PL(2,I)=C(I)
    DO 10 LL=2,ITT
      EL=LL
      LN=LL+1
      DO 11 I=1,IT
        11 PL(LN,I)=((2.E+00*EL-1.E+00)*C(I)*PL(LN-1,I)-(EL-1.0E+00)*PL(LN-
          1 2,I))/EL
      DO 10 CONTINUE
    C INITIALIZE ARRAY PC() USED FOR RUNNING SUMMATION
    DO 1 I=1,IT
      1 PC(I)=0.E+00
    C LOOPS 2 AND 3 CALCULATE EXPANSION COEFS. FOR FUNCTION F( )
    C VIA GAUSS-LEGENDRE QUADRATURE. THE COEFS. GO INTO ARRAY OL( )
    DO 3 LL=1,IT
      L=LL-1
      EL=FLOAT(L)
      SUM=0.E+00
      DO 2 I=1,IT
        2 SUM=SUM+H(I)*F(I)*PL(LL,I)
      3 OL(LL)=SUM*(EL+0.5E+00)
    C LOOPS 4 AND 5 RECONSTRUCT THE FUNCTION F() AS PC() USING THE
    C COEFS. OL() FOUND ABOVE, AND THE RMS-DEVIATION BETWEEN F() AND
    C PC() AS EACH ADDITIONAL TERM IN THE LEGENDRE SERIES IS ADDED.
    DO 5 J=1,IT
      RMS(J)=0.E+00
      DO 4 I=1,IT
        PC(I)=PC(I)+OL(J)*PL(J,I)
      4 RMS(J)=RMS(J)+(F(I)-PC(I))*(F(I)-PC(I))
      5 RMS(J)=SQRT(RMS(J)/FLOAT(IT))
      DO 7 I=1,IT
        II=I-1
      C WRITE/PUNCH THE VALUES OF THE EXP. COEFS. OL() ON NUNIT.
      IF ((NCRDS.EQ.1).OR.(NCRDS.EQ.3)).AND.((ITOT.EQ.1).OR.((ITOT.EQ.3)
        + )) WRITE (NUNIT,6) OL(II),II
      7 WRITE (6,8) II,OL(II),RMS(II)
      RETURN
      6 FORMAT (E25.14,X,15)
      8 FORMAT (1H ,20X,16,1PE38.15,E35.15)
    END

```

GAUS0100  
GAUS0110  
GAUS0120  
GAUS0130  
GAUS0140  
GAUS0150  
GAUS0160  
GAUS0170  
GAUS0180  
GAUS0190  
GAUS0200  
GAUS0210  
GAUS0220  
GAUS0230  
GAUS0240  
GAUS0250  
GAUS0260  
GAUS0270  
GAUS0280  
GAUS0290  
GAUS0300  
GAUS0310  
GAUS0320  
GAUS0330  
GAUS0340  
GAUS0350  
GAUS0360  
GAUS0370  
GAUS0380  
GAUS0390  
GAUS0400  
GAUS0410  
GAUS0420  
GAUS0430  
GAUS0440  
GAUS0450  
GAUS0460  
GAUS0470  
GAUS0480  
GAUS0490  
GAUS0500  
GAUS0510  
GAUS0520  
GAUS0530  
GAUS0540  
GAUS0550  
GAUS0560  
GAUS0570

```

C
C
C
SUBROUTINE GUSSET(Z,P,PI)
  THIS ROUTINE CALCULATES THE ABSCESSAE XKN(I)
  AND GAUSS-LEGENDRE WEIGHTS AKN(I) FOR NUMERICAL INTEGRATION
  VIA GAUSS-LEGENDRE QUADRATURE OF ORDER N
  DIMENSION Z(100),P(513),XKN(100),AKN(100)
  DIMENSION PL(100,100),OL(100),RMS(100),PC(100),H(100),C(100)
  EQUIVALENCE (C(I),XKN(I)),(H(I),AKN(I))
  COMMON /BK2/PL,OL,RMS,PC,C,H,ALBDO,LLLL,NCRDS,ITT,NRADI
  N=IT
  TOL=1.0E-14
  AA=2.0E+00/PI**2.0E+00
  AB=-62.5E+00/(3.0E+00*PI**4.0E+00)
  AC=15116.0E+00/(15.0E+00*PI**6.0E+00)
  AD=-12554474.0E+00/(105.0E+00*PI**8.0E+00)
  PI1=1.0E+00
  EN=FLOAT(N)
  NPI=N+1
  U=1.0E+00-(2.0E+00/PI)**2.0E+00
  D=1.0E+00/SQRT((EN+0.5E+00)**2.0E+00+U/4.0E+00)
  DO 1 I=1,N
    S=FLOAT(I)
    A=4.0E+00*S-1.0E+00
    AE=AA/A
    AF=AB/A**3.0E+00
    AG=AC/A**5.0E+00
    AH=AD/A**7.0E+00
    1 Z(I)=PI*(A+AE*AF+AG*AH)/4.0E+00
    DO 6 K=1,N
      X=COS(Z(K)*D)
      2 P(2)=X
    DO 3 NN=3,NPI
      ENN=FLOAT(NN-1)
      3 P(NN)=(12.0E+00*ENN-1.0E+00)*X*P(NN-1)-((ENN-1.0E+00)*P(NN-2))/ENN
      PNP=EN*(P(N)-X*P(NPI))/(1.0E+00-X*X)
      XI=X-P(NPI)/PNP
      XD=ARS(XI-X)
      XDD=XD-TOL
      IF (XDD) 5,5,4
    4 X=XI
    GO TO 2
    5 XKN(K)=X
    6 AKN(K)=2.0E+00*(1.0E+00-X*X)/(EN*P(N)+EN*P(N))
    DO 7 I=1,N
      Z(I)=0.00
    7 P(1)=0.00
    RETURN
  END

```

GUST0100  
 GUST0110  
 GUST0120  
 GUST0130  
 GUST0140  
 GUST0150  
 GUST0160  
 GUST0170  
 GUST0180  
 GUST0190  
 GUST0200  
 GUST0210  
 GUST0220  
 GUST0230  
 GUST0240  
 GUST0250  
 GUST0260  
 GUST0270  
 GUST0280  
 GUST0290  
 GUST0300  
 GUST0310  
 GUST0320  
 GUST0330  
 GUST0340  
 GUST0350  
 GUST0360  
 GUST0370  
 GUST0380  
 GUST0390  
 GUST0400  
 GUST0410  
 GUST0420  
 GUST0430  
 GUST0440  
 GUST0450  
 GUST0460  
 GUST0470  
 GUST0480  
 GUST0490  
 GUST0500  
 GUST0510  
 GUST0520  
 GUST0530  
 GUST0540  
 GUST0550  
 GUST0560

```

SUBROUTINE ANGLE(I*1,IANG)
  THIS ROUTINE IS TO BE USED TO REPLACE GUSET FOR THE PURPOSE
  OF USING AGAUX TO DO PHASE FUNCTION CALCULATIONS AT -IT-
  ANGLES BETWEEN 0 AND 180 DEGREES, RATHER THAN AT THE G-L
  QUADRATURE ABSCISSA VALUES.
  DIMENSION BK(100,100),OL(100),RMS(100),PC(100),C(100)
  COMMON /BK2/PL,OL,RMS,PC,C,H,ALBDO,LLLL,NCRDS,IT,ITT,NRADI
  RADS=PI/180.*EO
  DEL=180.*EO/FLOAT(IT-1)
  IF (IANG.EQ.2) GO TO 2
  DO 1 I=1,IT
    H(I)=DEL*FLOAT(I-1)
    C(I)=COS(H(I)*RADS)
  RETURN
2  READ (5,100) (H(I),I=1,IT)
  DO 3 I=1,IT
    C(I)=COS(H(I)*RADS)
  IANG=1
  RETURN
  FORMAT (16F5.1)
100
END

```





```

CAYT=0.0
POINT=0
H=0
WAVE=WVD
TMCHUR=TEMPO
IF (WAVE.LT.0.2.0R.WAVE.GT.200.0.0R.TMCHUR.LT.273.0R.
1 TMCHUR.GT.303.0) GO TO 11
C BINARY SEARCH
L=1
H=125
1 POINT=((L+H)/2)
TEST=ABS(LAMBDA(POINT)-WAVE)
IF (TEST.LE.0.0001) GO TO 4
IF (WAVE.GT.LAMBDA(POINT)) GO TO 2
H=POINT
GO TO 3
2 L=POINT+1
3 IF (L.NE.H) GO TO 1
L=L-1
C INTERPOLATION ROUTINE
EMT=NSUBR(L)+(NSUBR(L+1)-(NSUBR(L))*((WAVE-LAMBDA(L))/(LAMBDA(L+1)-LAMBDA(L))))
1 LAMBDA(L))
CAYT=NSUBI(L)+(NSUBI(L+1)-NSUBI(L))*((WAVE-LAMBDA(L))/(LAMBDA(L+1)-LAMBDA(L)))
1 -LAMBDA(L))
GO TO 5
4 CONTINUE
EMT=NSUBR(POINT)
CAYT=NSUBI(POINT)
C SEARCH TEMP VS DENS
5 IF (TMCHUR.LT.273.0.0R.TMCHUR.GT.303.0) GO TO 11
L=1
H=7
6 P=((L+H)/2)
TEST=ABS(TEMP(P)-TMCHUR)
IF (TEST.LE.0.0001) GO TO 9
IF (TMCHUR.GT.TEMP(P)) GO TO 7
H=P
GO TO 8
7 L=P+1
8 IF (L.NE.H) GO TO 6
L=L-1
RHODEN=DENS(L)+(DENS(L+1)-DENS(L))*((TMCHUR-TEMP(L))/(TEMP(L+1)-TEMP(L)))
1 GO TO 10
9 RHODEN=DENS(P)
10 CONTINUE
EMD=ENT
CAYD=CAYT
DENS=D-RHODEN
GO TO 13
11 WRITE (6,12) TMCHUR,WAVE
12 FORMAT (10H TEMP. OF ,E12.6,14H OR WAVE. OF ,E12.6,14H BEYOND RANWATX1170
1 27H OF DATA IN WATER ROUTINE/22H EXECUTION TERMINATED )
13 STOP
13 RETURN
END
WATX0660
WATX0670
WATX0680
WATX0690
WATX0700
WATX0710
WATX0720
WATX0730
WATX0740
WATX0750
WATX0760
WATX0770
WATX0780
WATX0790
WATX0800
WATX0810
WATX0820
WATX0830
WATX0840
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WATX0870
WATX0880
WATX0890
WATX0900
WATX0910
WATX0920
WATX0930
WATX0940
WATX0950
WATX0960
WATX0970
WATX0980
WATX0990
WATX1000
WATX1010
WATX1020
WATX1030
WATX1040
WATX1050
WATX1060
WATX1070
WATX1080
WATX1090
WATX1100
WATX1110
WATX1120
WATX1130
WATX1140
WATX1150
WATX1160
WATX1170
WATX1180
WATX1190
WATX1200
WATX1210

```

```

SUBROUTINE AGXPRT(SCATT,KEXTT,KSCAT,KBAKT,CATTN,IANG,ITOT,NUN,IT)
REAL KEXTT,KSCAT,KBAKT
DIMENSION F(513),K(513),C(100),PSUM(100),SCATT(100),SCAT(100)
DIMENSION PL(100,100),OL(100),RMS(100),PC(100),H(100),DR(8),RR(9)
COMMON /BK2/PL,OL,RMS,PC,C,H,ALBDO,LLLL,NCRDS,IT,ITT,MRADI
COMMON /BK3/F,R,PSUM,SCAT,RR,DR,WAVE,EM,CAY,EMH,PI,IDSTP,
+ MRTE,NKG,NHALV,NI
WRITE (6,3)
WRITE (6,4) KEXTT
WRITE (6,5) KSCAT
WRITE (6,6) KBAKT
WRITE (6,7) CATTN
IF (ITT.LT.2) GO TO 22
WRITE (6,8)
IF (IANG.EQ.0) GO TO 17
WRITE (6,11)
DO 16 J=1,IT,4
K=J+3
IF (K.GT.IT) K=IT
16 WRITE (6,14) (H(I),PSUM(I),I=J,K)
GO TO 19
17 WRITE (6,10)
DO 18 J=1,IT,4
K=J+3
IF (K.GT.IT) K=IT
18 WRITE (6,13) (C(I),PSUM(I),I=J,K)
WRITE (6,9)
C THE FOLLOWING PREVENTS AN EXTRA SET OF OL'S FROM BEING WRITTEN
C OUT ON NUNIT.
ITOT=5
CALL GAUS(PSUM,NUNIT,ITOT)
GO TO 22
19 WRITE (6,2)
WRITE (6,12)
DO 20 J=1,IT,4
K=J+3
IF (K.GT.IT) K=IT
20 WRITE (6,14) (H(I),SCATT(I),I=J,K)
22 RETURN
2 FORMAT (1H3,/,1X,45X,23HSCATTERING FRACTIONS/)
3 FORMAT (1H3,/,1X,45H RESULT IS AVERAGED OVER PARAMETER NWAVE FOLLOW/)
4 FORMAT (/,1X,20H EXTINCTION COEF. = ,5X,IPE12.5,9H (PEK KM))
5 FORMAT (/,1X,20H SCATTERING COEF. = ,5X,IPE12.5,9H (PEK KM))
6 FORMAT (/,1X,25H BACK-SCATTERING COEF. = ,IPE12.5,9H (PER KM))
7 FORMAT (/,1X,21H ATTENUATION COEF. = ,4X,IPE12.5,13H SQ-METERS/MG)
8 FORMAT (1H3,/,1X,55X,14HPHASE FUNCTION/)
9 FORMAT (1H3,/,1X,25X,1HL,20X,16HLTH COEFFICIENT,23X,5HRMS ,
+ 9HDEVIATION/)
10 FORMAT (1H3,3X,4(5H MU,8X,17HPHASE FUNCTION ))
11 FORMAT (1H3,18X,4(20H ANGLE PF-VALUE ))
12 FORMAT (1H3,18X,4(20H ANGLE SCAT ))
13 FORMAT (1H ,4(F13.9,E17.1))
14 FORMAT (1H ,18X,4(1X,F6.2,1X,E12.7))
END

```

PRTX0100  
 PRTX0170  
 PRTX0180  
 PRTX0190  
 PRTX0200  
 PRTX0210  
 PRTX0220  
 PRTX0230  
 PRTX0240  
 PRTX0250  
 PRTX0260  
 PRTX0270  
 PRTX0280  
 PRTX0290  
 PRTX0300  
 PRTX0310  
 PRTX0320  
 PRTX0330  
 PRTX0340  
 PRTX0350  
 PRTX0360  
 PRTX0370  
 PRTX0380  
 PRTX0390  
 PRTX0400  
 PRTX0410  
 PRTX0420  
 PRTX0430  
 PRTX0440  
 PRTX0450  
 PRTX0460  
 PRTX0470  
 PRTX0480  
 PRTX0490  
 PRTX0500  
 PRTX0510  
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 PRTX0530  
 PRTX0540  
 PRTX0550  
 PRTX0560  
 PRTX0570  
 PRTX0580  
 PRTX0590  
 PRTX0600  
 PRTX0610  
 PRTX0620  
 PRTX0630  
 PRTX0640  
 PRTX0650  
 PRTX0660  
 PRTX0670  
 PRTX0680  
 PRTX0690

```

SUBROUTINE GPHASX(PSUM,PL,COEF,EMU,EMO,W,PA,GFN,OM,PI,NUNIT,L,
+NRDS)
C THIS ROUTINE WILL COMPUTE THE GHG ANALYTIC PHASE FUNCTION WHEN
C IAPX .GT. ZERO. SUBROUTINES GUSSTX AND PRINTX ARE ALSO NEEDED.
C DIMENSION PSUM(100),PL(100,100),COEF(100),EMO(100),W(100),
+PA(100),GFN(100),OM(100)
DO 1 I=1,L
PL(I,I)=0.E0
EMO(I)=0.E0
EMO(1)=0.E0
W(1)=0.E0
PA(1)=0.E0
GFN(1)=0.E0
OM(1)=0.E0
C ASYMETRY FACTOR
TRUEG=COEF(2)/(3.E0*COEF(1))
C CALCULATE GAUSS-LEGENDRE WEIGHTS AND ANGLES, ORDER L
C CALL GUSSTX(EMO,EMU,PA,W,L,PI)
C CONSTRUCT ANGLES FROM COSINES
DO 2 I=1,L
EMO(I)=180.E0*ACOS(EMU(I))/PI
C CONSTRUCT LEGENDRE POLYNOMIALS
DO 15 J=1,L
PL(I,J)=1.E0
PL(2,J)=EMU(J)
DO 16 I=3,L
EI=I-1
DO 16 J=1,L
PL(I,J)=((2.E0*EI-1.E0)*EMU(J)*PL(I-1,J)-(EI-1.E0)*PL(I-2,J))/EI
C PHASE FUNCTION AT ZERO DEGREES
C=PSUM(1)/COEF(1)
ITR=0
DELL=0.1E0
ONE=1.E0
G=1.E0+DELL
TOLER=1.E-04
RHS=0.5E0*COEF(3)/COEF(1)
ITR=ITR+1
G=G-DELL
FAC1=1.E0-G
ELHS=G*(FAC1*FAC1*C-1.E0+1.5E0*G)
TEST=ELHS-RHS
IF (ABS(TEST/RHS).LE.TOLER) GO TO 3
C THE FOLLOWING INSURES THAT G STARTS AT 1. AND GOES DOWNWARD
IF ((ITR.EQ.1).AND.(TEST.GT.0.E0)) ONE=-ONE
TEST=ONE*TEST
IF (G.LT.0.E0) GO TO 14
IF (TEST.LE.0.E0) GO TO 4
G=G+DELL
DELL=DELL/PI
IF (ITR.EQ.100) GO TO 3
GO TO 4
GSQ=G*G
ALPHA=RHS/GSQ-0.5E0
FAC1=1.E0-GSQ
FAC2=1.E0+GSQ

```

```

      TWOG=2*EO*G
      HALF=0.5EO*ALPHA
      FAC3=1*EO-HALF
      FAC4=(ALPHA-2*EO)*G
      C   GUEDECKE PART OF PHASE FUNCTION
      DO 5 J=1,L
      DEN=FAC2-TWOG*EMU(J)
      DENOM=SQRT(DEN)
      TEMP=(HALF*FAC1/DEN+FAC3)/DENOM
      GPFN(J)=COEF(1)*TEMP
      C   PFN GOES NEG: USE HG FOR LATTER PART
      IF (TEMP*LT*O*EO) GO TO 6
      C   CONTINUE
      C   GHG PFN NOT NEG: SKIP HG PART
      GO TO 7
      J1=J-1
      FAC4=EMU(J1)*FAC4
      HG PFN
      DO 8 J=J1,L
      DEN=FAC2-TWOG*EMU(J)
      DENOM= SQRT(DEN)
      GPFN(J)=COEF(1)*((FAC2-ALPHA*GSQ*FAC4)/(DEN*DENOM)
      C   CONTINUE
      OMO=O*EO
      C   INTEGRATE GHG PFN FOR APPROXIMATE OMEGA ZERO
      DO 9 J=1,L
      OMO=OMO+GPFN(J)*W(J)
      OMO=O*5EQ*OMO
      C   RENORMALIZE
      DO 10 J=1,L
      GPFN(J)=COEF(1)*GPFN(J)/OMO
      C   CONSTRUCT APPROXIMATE LEGENDRE COEFFICIENTS
      DO 11 I=1,L
      EN=FLOAT(I-1)
      FAC1=EN*O*5EO
      DO 11 J=1,L
      OM(I)=OM(I)+FAC1*GPFN(J)*PL(I,J)*W(J)
      SUM=O*EJ
      PHASEO=O*EO
      DO 12 I=1,L
      C   ANALYTIC PFN AT ZERO DEGREES
      PHASEO=PHASEO+OM(I)
      C   INTEGRATE ANALYTIC PFN OVER THETA
      SUM=SUM+GPFN(I)*W(I)
      C   NOW OVER PHI
      SUM=SUM*2*EO*PI
      EHR=ABS(SUM-4*EO*PI*COEF(1))/(4*EO*PI*COEF(1))*100*EO
      CALL PRINTX (EMU,GPFN,OM,PHASEO,SUM,ERR,TRUEG,L,PSUM,NUNIT,NCRDS)
      RATIO1=(OM(1)-COEF(1))/COEF(1)*100*EO
      RATIO2=(OM(2)-COEF(2))/COEF(2)*100*EO
      RATIO3=(OM(3)-COEF(3))/COEF(3)*100*EO
      WRITE (6,100) RATIO1,RATIO2,RATIO3
      C   FORMAT (1X,/,1X,1X,26HPFNCENT ERRORS: OMEGA 0 = ,F8.3/,1X,26X,
      *1,HOMEGA 1 = ,F8.3/,1X,26X,1UHOMEGA 2 = ,F8.3)
      RETURN
      C   WRITE (6,101)
      C   FORMAT (1X,44H THERE EXISIS NO MATCHING G - PRG TERMINATED)

```

GPHX1230  
GPHX1240

STOP  
END

```

C
C
SUBROUTINE GUSSTX(EMO,EMU,PA,W,L,PI)
  THIS ROUTINE IS ESSENTIALLY THE SAME AS GUSET.
  EMU IS COS ANGLE AND W ARE WEIGHTS, EMO,PA ARE TEMPORARY.
  DIMENSION EMU(100),EMO(100),PA(100),W(100)
  TOL=1.0E-14
  N=L
  AA=2.0/PI**2
  AB=-62./13.*PI**4
  AC=15116./15.*PI**6
  AD=-12554474./105.*PI**8
  PA(1)=1.00E+00
  EN=N
  NP1=N+1
  U=1.00E+00-(2.00E+00/PI)**2
  D= 1.0E+00/SQRT((EN+0.5E+00)**2+U/4.0E+00)
  DO 1 I=1,N
    SM=1
    AZ=4.*SM-1.
    AE=AA/AZ
    AF=AB/AZ**3
    AG=AC/AZ**5
    AH=AD/AZ**7
    1 EMO(I)=0.25*PI*(AZ+AE+AF+AG+AH)
    DO 6 K=1,N
      X=COS(EMO(K)*D)
    2 PA(2)=X
    DO 3 NNN=3,NP1
      ENN=NNN-1
    3 PA(NNN)=((2.0E+00*ENN-1.0E+00)*X*PA(NNN-1)-(ENN-1.0E+00)*
      *PA(NNN-2))/ENN
      PNP=EN*(PA(N)-X*PA(NP1))/(1.0E+00-X*X)
      XI=X-PA(NP1)/PNP
      XD=ARS(XI-X)
      XDD=XD-TOL
      IF(XDD)5,5,4
    4 X=XI
    GO TO 2
    5 EMU(K)=X
    6 W(K)=2.0E+00*(1.0E+00-Y*X)/(EN*PA(N)+EN*PA(N))
  RETURN
END
GUSX0100
GUSX0110
GUSX0120
GUSX0130
GUSX0140
GUSX0150
GUSX0160
GUSX0170
GUSX0180
GUSX0190
GUSX0200
GUSX0210
GUSX0220
GUSX0230
GUSX0240
GUSX0250
GUSX0260
GUSX0270
GUSX0280
GUSX0290
GUSX0300
GUSX0310
GUSX0320
GUSX0330
GUSX0340
GUSX0350
GUSX0360
GUSX0370
GUSX0380
GUSX0390
GUSX0400
GUSX0410
GUSX0420
GUSX0430
GUSX0440
GUSX0450
GUSX0460
GUSX0470
GUSX0480
GUSX0490
GUSX0500

```

```

SUBROUTINE PRINTX(EMU,PHFN,COEFS,PHASEQ,SUM,ERROR,G,L,PSUM,NUNIT,
+NCRDS)
  DIMENSION EMU(100),PHFN(100),COEFS(100),PSUM(100),IO(4)
  WRITE (6,100) G
  WRITE (6,101) PSUM(1)
  WRITE (6,102) PHASEQ
  WRITE (6,103)
  DUMSCT=0.0
  DO 1 I=1,L
    IF ((NCRDS.EQ.2).OR.(NCRDS.EQ.3))
      WRITE (NUNIT,111) DUMSCT,PHFN(1),EMU(1),I
    +
  1 CONTINUE
    DO 4 I=1,L
      II=I-1
      IF ((NCRDS.EQ.1).OR.(NCRDS.EQ.3)) WRITE (NUNIT,110) COEFS(1),II
    4 CONTINUE
      DO 2 I=1,L,4
        K=I+3
        IF (K.GT.L) K=L
        WRITE (6,104) (EMU(J),PHFN(J),J=I,K)
        WRITE (6,105) COEFS(1),SUM,ERROR
        WRITE (6,106)
        WRITE (6,107)
        DO 3 I=1,L,4
          IO(1)=I
          IO(2)=I+1
          IO(3)=I+2
          IO(4)=I+3
          K=I+3
          IF (K.GT.L) K=L
          WRITE (6,108) (IO(J-1+1),COEFS(J),J=I,K)
          RETURN
        100 FORMAT (1H,30X,38H      GHG PHASE FUNCTION FOR ASYMMETRY ,
+13HFACTOR (G) = ,F7.4,/)
        102 FORMAT(1X,38X,43H      GHG PHASE FUNCTION AT ZERO DEGREES IS
+F9.4,/)
        103 FORMAT(1X,38X,43HCOMPUTED PHASE FUNCTION AT ZERO DEGREES IS ,
+F9.4,/)
        104 FORMAT (1X,50(1H-1,12H GHG VALUES ,50(1H-1/,
+1X,2X,4(15H MU,8X,17HPHASE FUNCTION )//)
        105 FORMAT(1X,/,1X,10X,14HTRUE OMEGAQ = ,F7.4,3X,33HINTEGRATED GHG PHAPNTX0510
+SE FUNCTION = ,F8.4,2X,20HAND PERCENT ERROR = ,F8.4)
        106 FORMAT (1X,/,1X,44X,20H      GHG COEFFICIENTS,/)
        107 FORMAT(1X,24X,4(6X,20H ,5X,5HOMEGA),/)
        108 FORMAT (28X,4(2X,12,2X,E12.6))
        109 FORMAT (E25.14,1X,15)
        110 FORMAT (3(E12.6,1X),15)
        111
      END

```



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